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

July 2025

Independent Statistics and Analysis
U.S. Energy Information Administration

www.eia.gov
U.S. Department of Energy
Washington, DC 20585

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Update Information

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

- Grew solar PV capacity such that added annual capacity meets or exceeds retirements across cases; in effect, assumed no PV retirement without replacement (AEO2023)
- Adjusted distributed generation, ground source heat pump, and solar water heater investment costs to reflect updated tax incentives provided by the Inflation Reduction Act (AEO2023)
- Dynamically phased-out ITC tax credits based on electric power sector emissions reductions, as specified in the Clean Electricity Investment Tax Credit (AEO2025)
- Replaced average fossil fuel heat rate conversion for solar PV and wind distributed generation, using the heat content of electricity, a constant conversion factor of 3,412 Btu/kWh, instead. We refer to this as the *captured energy* approach (AEO2025)
- Updated module base year to 2018, based on the *2018 Commercial Buildings Energy Consumption Survey (CBECS)*, and updated CDM's first projection year to 2019 (AEO2025)
- Updated floorspace growth rate coefficients, based on share of commercial floorspace types present in the 2018 CBECS; growth rates continue to be calculated in Macroeconomic Activity Module (MAM) (AEO2025)
- Expanded representation of data centers to account for data center energy use across all NEMS building types with data center rooms present (on-premises data centers), according to the 2018 CBECS (AEO2025)

Additional information regarding annual changes to modeling and assumptions can be found in the AEO Buildings Working Group materials.

1. Introduction

Purpose of the report

This report documents the objectives, analytical approach, and development of the National Energy Modeling System (NEMS) Commercial Demand Module (CDM, or module). The report catalogues and describes the model assumptions, computational methodology, parameter estimation techniques, model source code, and outputs generated through the use of the module.

This document serves three purposes. First, it is a reference document providing a detailed description for model analysts, users, and the public. Second, this report meets the legal requirement of the U.S. Energy Information Administration (EIA) to provide adequate documentation in support of its models (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 as future projects.

Model summary

The NEMS CDM is a simulation tool based on economic and engineering relationships that models commercial sector energy demands at the census division level of detail for 11 distinct categories of commercial buildings (Table 1). The CDM is used in developing long-term projections and energy policy analysis over the projection period beginning with our most recent *Commercial Buildings Energy Consumption Survey* (CBECS) (the module's base year) through 2050 (the current projection period). Commercial equipment selections are performed for the major fuels (electricity, natural gas, and distillate fuel oil) and for the major end-use services (space heating, space cooling, water heating, ventilation, cooking, lighting, and refrigeration). The market segment level of detail is modeled using a constrained life-cycle cost minimization algorithm that considers commercial sector consumer behavior and risk-adjusted time preference premiums. The algorithm also models demand for minor fuels (residual fuel oil, propane, steam coal, motor gasoline, and kerosene), renewable fuel sources (hydroelectric, solar energy, and wind, including biomass sources such as wood and municipal solid waste), and the minor services of computing, office equipment, and *other* or miscellaneous electric loads (MELs) in less detail than the major fuels and services. Commercial decisions regarding the use of distributed generation (DG) and combined-heat-and-power (CHP) technologies are performed using an endogenous cash-flow algorithm. Numerous specialized considerations are incorporated, including the effects of changing building shell efficiencies and consumption to provide district energy services.

As a component of the NEMS integrated projection tool, the Commercial Demand Module generates projections of commercial sector energy demand. The module facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they affect commercial sector energy demand.

Documentation

U.S. Energy Information Administration, *Commercial Demand Module of the National Energy Modeling System: Model Documentation*, DOE/EIA-M066 (2025) (Washington, DC, August 2025).

Archive media and installation manuals

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

Model archival citation

This documentation refers to the NEMS Commercial Demand Module as archived for the *Annual Energy Outlook 2025* (AEO2025).

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

Model contact

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Report organization

Chapter 2 of this report discusses the purpose of the model, detailing its objectives, primary input and output quantities, and its relationship to the other modules of the NEMSNEMS. Chapter 3 of the report describes the rationale behind the model design, providing insights into further assumptions used in the model development process to this point. Chapter 4 details the model structure, using graphics and text to illustrate model flows and key computations.

The appendixes to this report provide supporting documentation for the input data and parameter files. Appendix A lists and defines the input data used to generate parameter estimates and endogenous projections, along with the parameter estimates and the outputs of most relevance to the NEMSNEMS and the model evaluation process. A table referencing the equations in which each variable appears is also provided in Appendix A. Appendix B contains a mathematical description of the computational algorithms, including the complete set of model equations and variable transformations. Appendix C is a bibliography of reference materials used in the development process. Appendix D provides the model abstract, and Appendix E discusses data quality and estimation methods. Other analyses discussing alternative assumptions, sensitivities, and uncertainties in projections developed using the NEMS CDM are available at our website.

2. Model Purpose

Model objectives

The NEMS CDM serves three objectives. First, it develops projections of commercial sector energy demand, through the projection period,[1] as a component of the NEMS integrated projection system. The resulting projections are incorporated into the *Annual Energy Outlook*, published annually by EIA. Second, it is used as a policy analysis tool to assess the impacts on commercial sector energy consumption of changes in energy markets, building and equipment technologies, environmental considerations, and regulatory initiatives. Third, as an integral component of NEMS, it provides inputs to the Electricity Market Module (EMM), Coal Market Module (CMM), Natural Gas Market Module (NGMM), and Liquid Fuels Market Module (LFMM) of NEMS, contributing to the calculation of the overall energy supply and demand balance of the U.S. energy system.

The CDM projects commercial building sector energy demands in five sequential steps. These steps produce projections of new and surviving commercial building floorspace, demands for energy-consuming services in those buildings, generation of electricity by distributed generation technologies, technology choices to meet the end-use service demands, and consumption of electricity, natural gas, and distillate fuel oil by the equipment chosen.[2] These projections are based on energy prices and

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1 The base year for the Commercial Demand Module corresponds to the most recently available CBECS. Dynamic projections dependent on feedback from the rest of NEMS are made for the years following the base year through the projection period. We benchmark sector-level consumption results to historical estimates from our State Energy Data System and *Monthly Energy Review*.

2 The End-Use Consumption Module accounts for commercial sector consumption of five minor fuels: residual fuel oil, propane, steam coal, motor gasoline, and kerosene. These fuels do not account for enough commercial sector consumption to justify modeling at the same level of detail as the three major fuels. We also consider hydroelectric and other renewable fuel sources,

macroeconomic variables from NEMS, combined with external data sources. The CDM also projects *non-building* energy consumption associated with select miscellaneous electric loads in the commercial sector, discussed in fuller detail in this document.

The NEMSNEMS uses the projected commercial sector fuel demands generated by the CDM to calculate the supply and demand equilibrium for individual fuels. In addition, the NEMS supply modules referenced previously use the commercial sector outputs in conjunction with other projected sector demands to determine the patterns of consumption and the resulting amounts and prices of energy delivered to the commercial sector.

Of equal importance, the NEMS CDM is relevant to the analysis of current and proposed legislation, private sector initiatives, and technological developments. The flexible model design provides a policy analysis tool able to accommodate a wide range of scenario developments. We have specially developed both the input file structure and the model source code to facilitate scenario (*what if*) analyses of energy markets, technology characterizations, market initiatives, environmental concerns, and regulatory policies such as demand-side management (DSM) programs. Specific policy analyses that can be addressed using this model include assessing the potential impacts of:

- New end-use technologies
- New energy supply technologies
- Federal, state, and local government policies, including:
    - Changes in fuel prices as a result of tax policies
    - Changes in building shell or equipment energy efficiency standards
    - Financial incentives for energy efficiency or renewable energy investments
- Information programs
    - Environmental standards
- Utility demand-side management (DSM) programs

Model input and output

Inputs

The primary inputs to the CDM include fuel prices, commercial building floorspace growth, interest rates, and technology cost and performance parameters.[3] The technology characteristics used by the model for distributed generation technologies are included in the summary of major inputs that follows. Appendix A contains additional detail on model inputs.

Inputs to Floorspace Submodule

- Existing distribution of commercial building floorspace stock in the CDM base year
- Median construction year of existing commercial buildings by type, vintage, and location
- Building survival parameters

including waste heat and biomass sources such as wood and municipal solid waste, as well as other gaseous fuels at a lesser level of detail than the major fuels.

[3] End-use technology characteristics are based on reports completed for EIA by Leidos, Inc., and Navigant Consulting, Inc., See the detailed description of module inputs in Appendix A for full citation.

- Commercial building floorspace growth

Inputs to Service Demand Submodule

- Energy use intensities (EUIs) in the base year
- Commercial technology characterizations
    - Market share of equipment existing in the base year
    - Equipment efficiency
    - Building restrictions
    - Service provided
    - Fuel used
- Building shell efficiency load factors (heating and cooling) and shell efficiency improvement through the projection period for existing and new floorspace
- Market penetration projections for office equipment and miscellaneous electric loads (MELs) categories
- Market penetration projections for building sensors and control technologies
- Steam EUIs to provide district energy services in the base year
- Efficiencies of district energy systems in the base year
- Fuel shares of district energy service steam production in the base year
- Short-run price elasticities of service demand
- Historical and projected heating and cooling degree days
- Differences in serviced floorspace proportions between existing and new floorspace

Inputs to Distributed Generation (DG)/CHP Submodule

- DG and CHP technology characteristics
    - Fuel used
    - First and last year of availability for purchase of system
    - Generation capacity
    - Capital cost per kilowatt of capacity
    - Installation cost per kilowatt of capacity
    - Operating and maintenance cost per kilowatt of capacity
    - Inverter replacement cost per kilowatt of capacity (solar photovoltaic and wind systems)
    - Inverter replacement interval (solar photovoltaic and wind systems)
    - Equipment life
    - Tax life and depreciation method
    - Available federal tax credits
    - Generation and thermal heat recovery efficiency
    - Annual operating hours
- Grid interconnection limitation parameters
    - Learning function parameters
    - Capital cost adjustment parameters for peak capacity scale adjustments
    - Renewable portfolio standard credit parameters
- Financing parameters
- Building-size category characteristics within building type

  - Average annual electricity use
  - Average building size in square feet
  - Share of floorspace
- Niche market scaling and price variables
  - Solar insolation
  - Average wind speed
  - Electricity rates relative to census division average
  - Natural gas rates relative to census division average
  - Roof area per unit of floorspace area
- Program-driven market penetration projections for distributed generation technologies
- Bass diffusion parameters for projecting future penetration, by census division and technology
- Historical CHP generation of electricity data

Inputs to Technology Choice Submodule

- Consumer behavior rule segments by building type, service, and decision type
  - Shares of consumers choosing from all technologies, from those using the same fuel, and from different versions of the same technology
- 10-year Treasury note rate
- Consumer risk-adjusted time preference premium segments
- Price elasticity of hurdle (implicit discount) rates
- Minor service efficiency improvement projections
- Building end-use service capacity utilization factors
- Commercial technology characterizations
  - First and last year of availability for purchase of system
  - Market shares of equipment existing in the base year
  - Installed capital cost per unit of service demand
  - Operating and maintenance cost per unit of service demand
  - Equipment efficiency
  - Removal and disposal cost factors
  - Building restrictions
  - Service provided
  - Fuel used
  - Expected equipment lifetimes
  - Cost trend parameters
  - Quality factor (lighting only)
- Expected fuel prices

Inputs to End-Use Fuel Consumption Submodule

- *Short-Term Energy Outlook* (STEO) consumption projections
- *Monthly Energy Review* (MER) consumption information
- State Energy Data System (SEDS) consumption information
- Components of SEDS data attributable to other sectors
- Minor fuel regression parameters

Outputs

The primary output of the Commercial Demand Module is projected commercial sector energy consumption by fuel type, end use, building type, census division, and year. The module also provides annual projections of the following for the commercial sector:

- Construction of new floorspace by building type and census division
- Surviving floorspace by building type and census division
- Equipment market shares by technology, end use, fuel, building type, and census division
- Distributed generation (DG) and Combined heat and power (CHP) generation of electricity
- DG and CHP electricity generation capacity
- Quantities of fuel consumed for DG and CHP
- Consumption of fuels to provide district energy services
- Non-building consumption of fuels in the commercial sector
- Average efficiency of equipment mix by end use and fuel type

Variable classification

The NEMS demand modules exchange information with the supply modules at the census-division level of detail spatially and average annual level temporally. Information exchanged between the CDM and the Electricity Market Module is also required at the end-use service level of detail. The input data available from our most recent *Commercial Buildings Energy Consumption Survey* (CBECS), which forms an important element of the statistical basis for the CDM, and other sources are designed to be statistically significant at various levels (some of which are above the census-division level). CDM variables are resolved at a relatively fine level of detail to capture heterogeneous effects that manifest themselves at a high level of aggregation, yet which originate from variations at a disaggregate level. The characteristics represented by key variables are presented in Table 1, which also shows the notation generally used for each characteristic in this report.

Table 1. Categorization of key variables

Dimension subscript: index value	Census division R	Building type b	End-use service s	Category	Fuel F	Category
1	New England	Assembly	Space heating	Major	Electricity	Major
2	Middle Atlantic	Education	Space cooling		Natural gas	
3	East North Central	Food sales	Water heating		Distillate fuel oil	
4	West North Central	Food service	Ventilation		Residual fuel oil	Minor
5	South Atlantic	Health care	Cooking		Propane	
6	East South Central	Lodging	Lighting		Steam coal	
7	West South Central	Office—large (more than 50,000 square feet)	Refrigeration		Motor gasoline	
8	Mountain	Office—small (less than or equal to 50,000 square feet)	Computing	Minor	Kerosene	
9	Pacific	Mercantile and service	Office equipment		Wood	Renewables
10		Warehouse	Other		Municipal solid waste (MSW)	
11	U.S. total	Other			Hydroelectric	
12					Waste heat	Other
13					Other gaseous fuels (OGF)	

In addition to the characteristics shown in Table 1, over which most CDM variables vary, several other characteristics are represented by specific subsets of variables. These characteristics are represented through the use of the subscripts listed alphabetically in Table 2. The subscripts are described briefly below, with additional detail provided in Chapter 4.

Consumer risk-adjusted time preference premium segments are represented by the subscript *p*, and they represent the percentage increment to the risk-free interest rate in the current year, used to segment commercial consumer behavior patterns. The model uses a discrete distribution of seven consumer risk-adjusted time preference premiums to characterize the commercial consumer decision-making population. These seven discount premiums and the proportion of consumers attributed to each are allowed to vary annually by end use. The risk-free interest rate and the risk-adjusted time preference premiums account for the consumer hurdle (or implicit discount) rates used in equipment purchase decisions. Chapter 4 contains additional detail.

Table 2. Subscripts for CDM variables

Subscript	Potential range	Description
mc	1 through 13	Miscellaneous electricity use category. Category index for specific category of electricity use within MELs.
ntek	1 through 11	Technology number. Technology type for distributed generation or CHP systems.
P	1 through 7	Consumer risk-adjusted time preference premium segment. Component of the consumer hurdle rate.
t	1 through 60	Technology class. General technology type for end-use energy-using equipment.
v	1 through 50	Technology vintage. Specific vintage or model within a technology class.
y	1 through 62	Time dimension for CDM variables. A value of 1 corresponds to the year 1990 and a value of 61 corresponds to 2050. A value of 62 refers to equipment that is used as a placeholder or otherwise not chosen during the projection period.

Equipment defined in the Commercial Sector Technology Characterization Database, KTEKX, is represented by two subscripts, namely *t* and *v*. The existence of a particular pair of indexed values of *t* and *v* indicates that equipment within a technology class (*t*) is available in one or more vintages (*v*) (or models) available at different times throughout the projection period for competition in the Technology Choice Submodule. The current Technology Choice Submodule allows for a maximum of 44 vintages for each type of representative equipment. For example, two different vintages for the same technology class are 1) a 67.9 lumens per watt LED PAR38 (reflector) lightbulb available in 2018 and 2) a 93.0 lumens per watt high-efficacy LED PAR38 bulb available in 2022 and beyond.

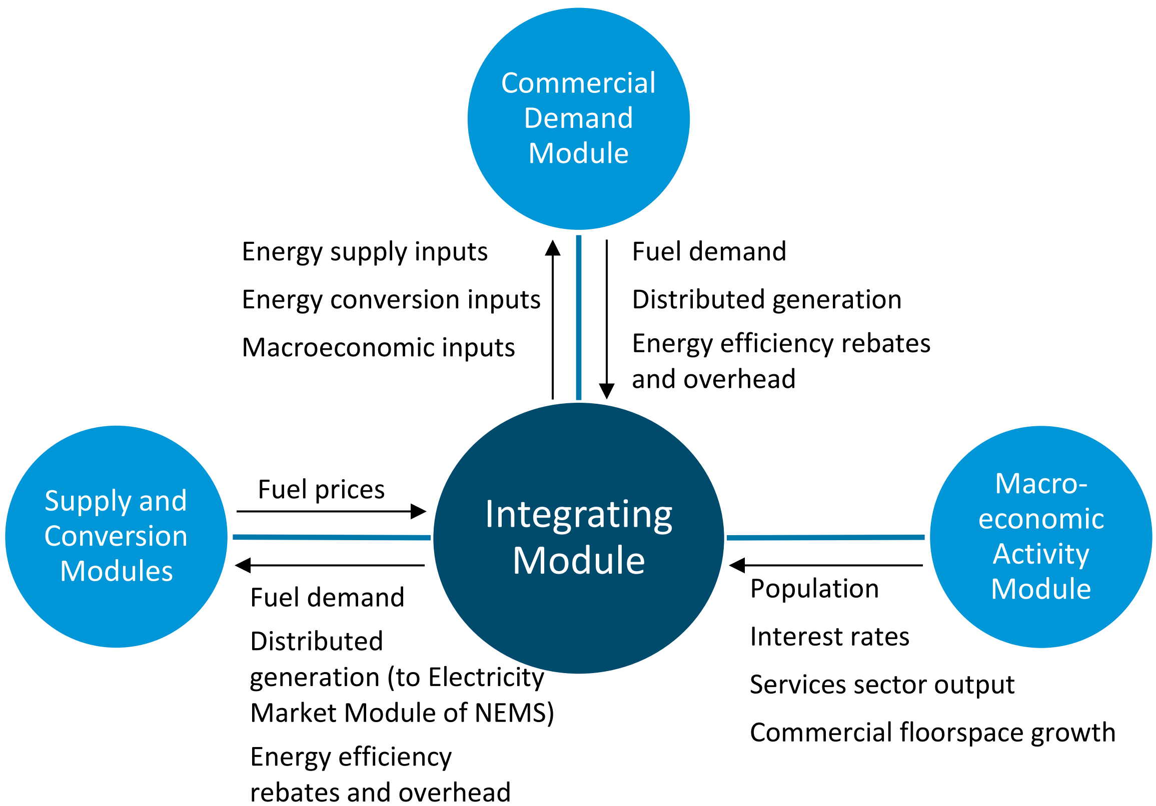
The Technology Choice Submodule models the major service end uses listed in Table 1 (Chapter 4). We project minor end uses using equipment efficiency and market penetration trends. Projected energy demand for the major fuels listed in Table 1 take into account the price elasticity of service demand and efficiency *rebound* effects. We project minor fuel demands from historical census division-level consumption, floorspace, and fuel prices. Chapter 4 further describes the modeling methodology for projecting minor end uses and fuel demand and the considerations just mentioned.

Relationship to other NEMS modules

Figure 1 schematically depicts the relationship of the CDM to other components of NEMS. The CDM receives input data from the Macroeconomic Activity Module (MAM) and the energy supply modules. We use the commercial floorspace projections and interest rates generated by the MAM to calculate annual new additions to floorspace and annualized technology capital costs, respectively. Energy prices generated by the supply modules (specifically the end-use service electricity prices from the EMM, the natural gas prices from the NGMM, and the petroleum prices from the LFMM) are primary drivers for technology cost comparisons, projections of commercial sector distributed generation, and price foresight scenarios. The CDM provides energy consumption projections by census division and fuel to the supply modules listed above, from which supply resources and capacity plans are developed.

As shown in Figure 1, all exchanges of information between the modules take place through the NEMS Global Data Structure. The NEMS Integrating Module directs the activation of the sectoral modules, thus controlling the sequence and iteration of modeled elements at the sector level. The Integrating Module documentation and the NEMS Overview provide a more detailed description of the approach taken by the Integrating Module in interactions between the U.S. energy markets and the economy.

Figure 1. CDM's relationship to other NEMS modules



3. Model Rationale

Theoretical approach

The Commercial Demand Module (CDM) uses a simulation approach to project energy demands in commercial buildings, using the latest CBECS to inform assumptions for the CDM base year. The specific approach of the CDM involves explicit economic and engineering-based analysis of the building energy end uses of space heating, space cooling, water heating, ventilation, cooking, lighting, refrigeration, computing, office equipment, and other end uses. We model these end uses for 11 distinct categories of commercial buildings at the census-division level of detail.

The model is a sequentially structured system of algorithms; succeeding computations use the outputs of previously executed routines as inputs. For example, the building square footage projections developed in the floorspace routine are used to calculate demands of specific end uses in the service demand routine. Calculated service demands provide input to the Technology Choice subroutine and subsequently contribute to the development of end-use consumption projections.

In the default mode, the CDM assumes myopic foresight with respect to energy prices, using only currently known energy prices in the annualized cost calculations of the technology selection algorithm. The module can accommodate the alternative scenarios of adaptive foresight and perfect foresight within the NEMSNEMS.

The CDM can model equipment efficiency legislation as it continues to evolve. A key assumption is the incorporation of the equipment efficiency standards described in the Energy Policy Act of 1992 (EPACT92), the Energy Policy Act of 2005 (EPACT05), and the Energy Independence and Security Act of 2007 (EISA).[4] In addition, residential-type equipment used in commercial buildings, such as room air conditioners, is subject to provisions contained in the National Appliance Energy Conservation Act of 1987 (NAECA). We model these laws in the technology characterization database by ensuring that all available choices for equipment covered by these laws meet the required efficiency levels. As the U.S. Department of Energy continues to promulgate and update efficiency standards under EPACT92, EPACT05, EISA, and NAECA, we model changes by eliminating noncompliant equipment choices and introducing compliant equipment choices by the year the new standards take effect. In addition, we apply rebates to appliances meeting ENERGY STAR® or greater efficiency standards to reflect energy efficiency program expenditures.

Fundamental assumptions

Floorspace Submodule

When the model runs begin, the existing stock, geographic distribution, building usage distribution, and vintaging of floorspace are assumed to be the same as the floorspace published in the 2018 CBECS.[5]

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[4] For a detailed description of CDM handling of legislative provisions that affect commercial sector energy consumption, including EISA provisions and EPACT05 standards and tax credit provisions, see the Commercial Demand Module and Summary of Legislation and Regulations sections of *Assumptions to the Annual Energy Outlook*.

[5] U.S. Energy Information Administration. *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files. Washington, DC, December 2022.

We assume building shell characteristics for new additions to the floorspace stock through the projection period to at least conform to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2004.[6] We assume additional improvement for new construction to account for adoption of the ASHRAE 90.1-2007, ASHRAE 90.1-2010, ASHRAE 90.1-2013, and ASHRAE 90.1-2016 standards for building shell measures.

Service Demand Submodule

The average efficiency of the existing stock of equipment for each service is calculated to produce the CBECS energy consumption when the energy use intensities (EUIs) derived from the CBECS data are applied.

The model uses a simplified equipment retirement function under which the proportion of equipment of a specific technology class and model that retires annually is equal to the reciprocal of that equipment's expected lifetime, expressed in years.

We assume service demand intensity (SDI) is constant over the projection period (for each service, building type and vintage, and census division). We assume the primary components of the SDI calculation, EUIs, and average equipment efficiencies change over time in a manner that preserves the SDI.

We assume the market for the largest major services is saturated in all building types in all census divisions. No increase in market penetration for the services of space conditioning, water heating, ventilation, cooking, refrigeration, and lighting is modeled. However, demand for these services grows as floorspace grows with new additions projected by the Floorspace Submodule.

Technology Choice Submodule

The technology selection approach employs explicit assumptions regarding commercial consumer choice behavior. Consumers are assumed to follow one of three behavioral rules: least-cost, same-fuel, or same-technology. We develop the proportion of consumers that follows each behavioral rule based on quantitative assessment and specific assumptions that are in Appendix A.

The technology selection is performed using a discrete distribution of consumer risk-adjusted time preference premiums. We develop these premiums based on analysis of survey results and additional literature, employing specific assumptions about consumer behavior to quantify these concepts for inclusion in the model. Myopic foresight is assumed in the default mode of the model operation. In other words, current energy prices are used to develop the annualized fuel costs of technology selections in the default mode. Documentation of these assumptions is in Appendix A.

Energy efficiency and continuing market penetration for minor services (computing, office equipment, and MELs) increase during the projection period based on published sources that are further referenced

[6] Regional building shell efficiency parameters that reflect current building codes and construction practices, relative to the existing building stock in the base year, were developed from analysis reports prepared for EIA by Leidos (formerly Science Applications International Corporation). See the detailed description of building shell heating and cooling load factors in Appendix A for full citation.

in Appendix A. Computing and office equipment are assumed to consume only electricity, and fuel switching is not addressed.

4. Model Structure

Structural overview

The commercial sector encompasses establishments that are not engaged in industrial or transportation activities; the commercial sector is thus a residual category that encompasses a wide range of non-residential activities. These establishments include businesses such as stores, restaurants, hospitals, and hotels that provide specific services, as well as organizations such as schools, correctional institutions, and places of worship. In the commercial sector, energy is consumed mainly in buildings, while additional energy is consumed by non-building services including streetlights and municipal water services.[7]

Energy consumed in commercial buildings is the sum of energy required to provide specific energy services using selected technologies. New construction, surviving floorspace, and equipment choices projected for previous time periods largely determine the floorspace and equipment in place in future time periods. The model structure carries out a sequence of six basic steps for each projection year:

1. Project commercial sector floorspace.
2. Project the energy services (for example, space heating and lighting) required by that building space.
3. Project electricity generation and energy services to be met by distributed generation technologies.
4. Select specific end-use technologies (for example, natural gas furnaces and fluorescent lights) to meet the demand for energy services.
5. Determine the amount of energy consumed by the equipment chosen to meet the demand for energy services.
6. Benchmark consumption results to published historical data.

General considerations involved in each of these processing steps are examined below. Following this structural overview, flow diagrams are provided illustrating the general model structure and fundamental process flow of the NEMS CDM, the flow within the controlling component, and the process flow for each of the steps carried out in developing fuel demand projections. Finally, the key computations and equations for each of the projection submodules are given.

Commercial building floorspace projection

Commercial sector energy consumption patterns depend on numerous factors, including the composition of commercial building and equipment stocks, regional climate, and building construction variations. The NEMS CDM first develops projections of commercial floorspace construction and retirement by type of building and census division. We project floorspace for 11 building types:

[7] Energy consumption that is not attributed to buildings is discussed in the End-Use Consumption section.

- Assembly
- Education
- Food sales
- Food services
- Health care
- Lodging
- Office—large
- Office—small
- Mercantile and service
- Warehouse
- Other

Service demand projection

Once the building inventory is defined, the model projects demand for energy-consuming services within buildings. Consumers do not demand energy per se but rather the services that energy provides.[8] We measure this demand for delivered forms of energy in British thermal units (Btu) *out* in the CDM to distinguish it from the consumption of fuel, measured in Btu *in*, necessary to produce the useful services. We track 10 end-use services, based in part on the level of detail available from published survey work discussed further in this report:

- Space heating
- Space cooling
- Ventilation
- Other
- Water heating
- Lighting
- Cooking
- Refrigeration
- Computing
- Office equipment

The energy intensity of usage, measured in British thermal units per square foot, differs across service and building type. For example, health care facilities typically require more space heating per square foot than warehouses. Intensity of usage also varies across census divisions. Educational buildings in the New England Census Division typically require more heating services than educational buildings in the South Atlantic Census Division. As a result, total service demand for any service depends on the number, size, type, and location of buildings.

In each projection year, a proportion of energy-consuming equipment wears out in existing floorspace, leaving a gap between the energy services demanded and the equipment available to meet this demand. The efficiency of the replacement equipment, along with the efficiency of equipment chosen for new floorspace, is reflected in the calculated average efficiency of the equipment stock.

Consumers may increase or decrease their usage of a service in response to a change in energy prices. The model accounts for this behavioral impact by adjusting projected service demand using price elasticity of demand estimates for the major fuels of electricity, natural gas, and distillate fuel oil.[9] For electricity, the model uses a weighted-average price for each end-use service and census division. For the other two major fuels, the model uses a single average annual price for each census division. In performing this adjustment, the model also takes into account the effects of changing technology

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[8] Lighting is a good example of this concept. It is measured in lumens, units that reflect consumers' perception of the level of service received.

[9] The calculation described is actually performed on projected fuel consumption by the End-Use Consumption Submodule, making use of the direct proportionality between consumption and service demand. This method is necessary because the fuel shares of provided services are not determined until after selection of the equipment mix by the Technology Choice Submodule.

efficiencies and building shell efficiencies on the marginal cost of the service to the consumer, resulting in a secondary *take-back* (or *rebound*) effect modification of the pure price elasticity.

Decision to generate or purchase electricity

The Distributed Generation and CHP submodule projects electricity generation, fuel consumption, and water and space heating supplied by distributed generation technologies. We use historical data to derive CHP electricity generation through 2021. In addition, program-driven installation of solar photovoltaic systems, wind turbines, and fuel cells are input based on information from the U.S. Department of Energy (DOE) and industry associations (Appendix A). After 2021, distributed and CHP electricity generation projections are developed based on economic returns. The module uses a detailed cash-flow approach to estimate the internal rate of return on investment. Penetration of distributed and CHP generation technologies is a function of payback years, which are calculated based on the internal rate of return.

Equipment choice to meet service needs

Given the level of energy services demanded, the algorithm then projects the class and model of equipment selected to satisfy the demand. Commercial consumers purchase energy-using equipment to meet three types of demand:

- New—service demand in newly-constructed buildings (constructed in the current projection year)
- Replacement—service demand formerly met by retiring equipment (equipment that is at the end of its useful life and must be replaced)
- Retrofit—service demand that either continues to be met by existing equipment (retained equipment) or is formerly met by equipment at the end of its economic life (equipment with a remaining useful life that is nevertheless subject to retirement on economic grounds)

We refer to each type of demand as a *decision type*.

One possible approach to describe consumer choice behavior in the commercial sector would require the consumer to choose the equipment that minimizes the total expected cost over the life of the equipment. However, empirical evidence suggests that traditional cost-minimizing models do not adequately account for the full range of economic factors that influence consumer behavior. The NEMS CDM allows for the use of several possible assumptions about consumer behavior:

- Buy the equipment with the minimum life-cycle cost
- Buy equipment that uses the same fuel as existing or retiring equipment, but minimizes life-cycle costs under that constraint
- Buy (or keep) the same technology as the existing or retiring equipment, but choose between models with different efficiency levels based on minimum life-cycle costs

These behavior rules are designed to represent the range of economic factors that are empirically observed to influence consumer decisions. The consumers who minimize life-cycle cost are the most sensitive to energy price changes; thus, the price sensitivity of the model depends in part on the share of consumers using each behavior rule. The proportion of consumers in each behavior rule segment varies by building type, the end-use service under consideration, and decision type for the three decision types of new construction, replacement, or retrofit.[10]

We designed the model to choose among a discrete set of technologies exogenously characterized by commercial availability, capital cost, operating and maintenance (O&M) cost, removal and disposal cost, efficiency, and equipment life. The *menu* of equipment cost and performance depends on technological innovation, market development, and policy intervention. The design can accommodate a changing menu of technologies, recognizing that changes in energy prices and consumer demand may significantly change the set of relevant technologies the model user wishes to consider. The model includes an option to allow endogenous price-induced technology change in the determination of equipment costs and availability for the menu of equipment. This concept allows future technologies faster diffusion into the marketplace if fuel prices increase markedly for a sustained period.

Energy efficiency rebates

The model deducts rebates from installed cost for energy-efficient heating, cooling, ventilation, lighting, and water heating end-use technologies, reflecting program expenditures by utility and state program administrators to encourage energy efficiency. Energy efficiency rebates are often provided at the utility and local levels, but the NEMS CDM does not represent this level of granularity. It assumes rebate levels at the census-division level by technology type. Table 3 shows rebate levels for 2020 by end use for energy efficiency technologies. Lighting rebates begin to phase out after 2020 as light-emitting diodes (LEDs) approach market saturation, and certain appliance rebates may change slightly over time as the incremental cost of the technology changes.

Table 3. Commercial energy efficiency rebates in 2024

percentage of installed cost

Equipment type	New England	Middle Atlantic	East N. Central	West N. Central	South Atlantic	East S. Central	West S. Central	Mountain	Pacific
Rooftop air-source heat pump (ENERGY STAR/high efficiency)	3%	8%	6%	2%	11%	2%	1%	5%	28%
Natural gas furnace	7%	12%	0%	1%	0%	0%	0%	0%	2%
Ground-source heat pump (mid to high efficiency)	21%	17%	2%	0%	0%	0%	0%	0%	0%
Rooftop AC[a]	3%	2%	2%	2%	2%	2%	1%	2%	4%
Residential-type central AC	4%	4%	3%	3%	2%	1%	11%	3%	6%
Natural gas water heater	9%	8%	3%	3%	0%	0%	6%	5%	5%
Compact fluorescent bulbs	0%	0%	0%	0%	0%	0%	0%	0%	0%
LED PAR38, LED A Lamps[b]	5%	5%	5%	5%	5%	5%	5%	5%	5%
LED Integrated Luminaire[b]	9%	9%	9%	9%	9%	9%	9%	9%	9%

Source: U.S. Energy Information Administration (EIA), Northeast Regional Energy Efficiency Database (REED) 2021 data update; U.S. Energy Information Administration, *Northeast Regional Energy Efficiency Database (REED), Program and Measure Data: Report on Results of Investigations*, May 2020; U.S. Energy Information Administration, *Assessing Existing Energy Efficiency Program Activity*, June 2018; U.S. EPA, ENERGY STAR summaries of programs available at the *Database for Incentives and Joint Marketing Exchange*; and Consortium for Energy Efficiency (CEE) Program Resources

[a] Air conditioning

[b] Rebates for LEDs are drawn down through and eliminated after 2029 as technology achieves penetration.

[10] Additional detail regarding the derivation of the choice proportions is provided in Appendix A to this report.

Energy consumption

Following the choice of equipment to satisfy service demand, the model computes the total amount of energy consumed. To calculate energy use, the fuel shares of service resulting from the selected mix of equipment, together with the average efficiency of that mix, are applied to service demand. Table 4 shows an example of this calculation. If 100 million Btu of heating service demand in new office buildings in New England is required, then the calculations proceed as follows: allocate service demand according to the share of each fuel (Table 4, Column 3) and then divide service demand (Column 3) by the average efficiency (Column 4) to derive fuel consumption by fuel type.

Table 4. Energy consumption calculation example

	Service demand (100 MMBtu[11] out)			
Fuel (1)	Proportion of service demand (2)	Amount of service delivered (MMBtu out) (3) = (2)*100	Average efficiency (Btu out/Btu consumed) (4)	Fuel consumption (MMBtu) (5) = (3)/(4)
Distillate fuel oil	0.5	50.0	0.75	66.7
Electricity	0.3	30.0	0.87	34.5
Natural gas	0.2	20.0	0.80	25.0
Total				126.2

Projected building energy consumption is then benchmarked to the State Energy Data System (SEDS) historical commercial sector consumption, applying an additive correction term to ensure that simulated model results correspond to published SEDS historical values. This benchmarking adjustment accounts for non-building commercial sector energy consumption (for example, radio transmission towers) and provides a consistent starting point for the projection. The benchmarking procedure is further discussed in the last section of the main text of this report.

Flow diagrams

Figure 2 illustrates the general model flow of the NEMS CDM. The flow proceeds sequentially; each succeeding submodule uses as inputs the outputs of preceding submodules. The basic processing flow used by the CDM to generate its projection of fuel demands consists of six steps:

1. A projection of commercial building floorspace is generated based on input from the Macroeconomic Activity Module and results from previous years (COMFloorspace Submodule).
2. Demands for services are calculated for that distribution of floorspace (COMServiceDemand Submodule).
3. DG and CHP technologies are chosen to meet electricity demand in place of purchased electricity where economical (CDistGen).
4. Equipment is chosen to satisfy the demands for services (COMTechnologyChoice Submodule).

[11] Million British thermal units

5. Fuel consumption is calculated based on the chosen equipment mix, and additional commercial sector consumption components, such as those resulting from nonutility generation of electricity and district energy services, are accounted for (COMConsumption Submodule).
6. Results by fuel and census division are adjusted to match SEDS historical data, historical estimates from the *Monthly Energy Review*, and optionally the forecasts of the *Short-Term Energy Outlook* (COMBenchmarking Submodule).

The CDM is activated one or more times during each year of the projection period by the NEMS Integrating Module. Each time the module is activated, the processing flow follows the outline shown in Figure 2. Details of the processing flow within each of the CDM's submodules, together with the input data sources accessed by each, are shown in Figure 3 through Figure 9 and are summarized below. The precise calculations performed at the program subroutine level are described in the next section.

Figure 3 illustrates the flow within the controlling submodule of the CDM, COMM. This submodule retrieves user-specified options and parameters, performs certain initializations, and directs the processing flow through the remaining submodules. It also detects the conclusion of the projection period, and it directs the generation of detailed reports and output databases to the extent specified by the user.

Figure 4 illustrates the processing flow within the Floorspace Submodule of the module, COMFloorspace. The Floorspace Submodule requires the MAM total commercial floorspace growth projection by census division, building type, and year. In addition, the Floorspace Submodule uses base-year building stock characteristics and building survival parameters (developed based on analysis of CBECS data and additional sources as further referenced in Appendix A) to evolve the existing stock of floorspace into the future.

Figure 2. CDM structure and fundamental process flow

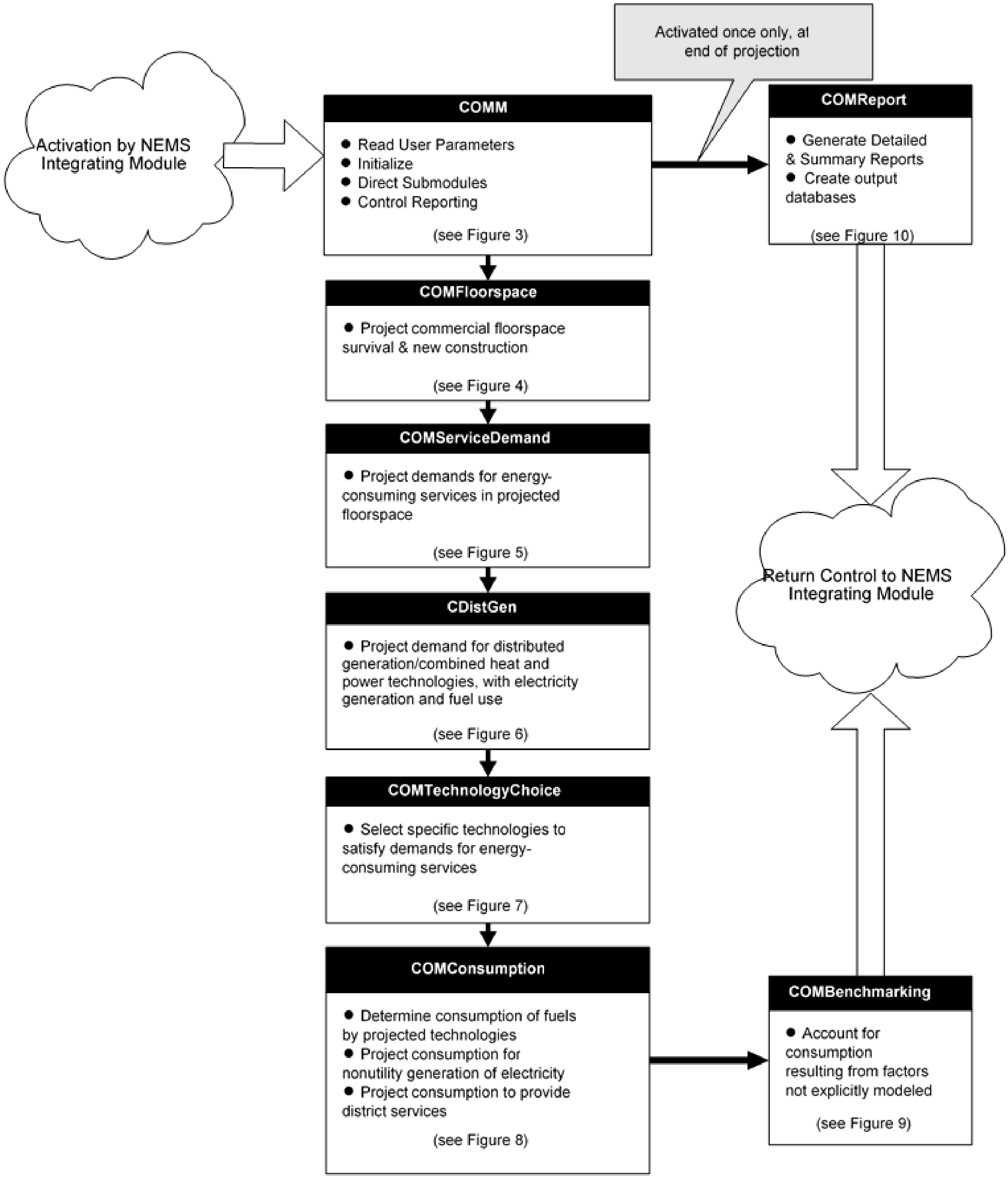


Figure 3. COMM calculation process flow

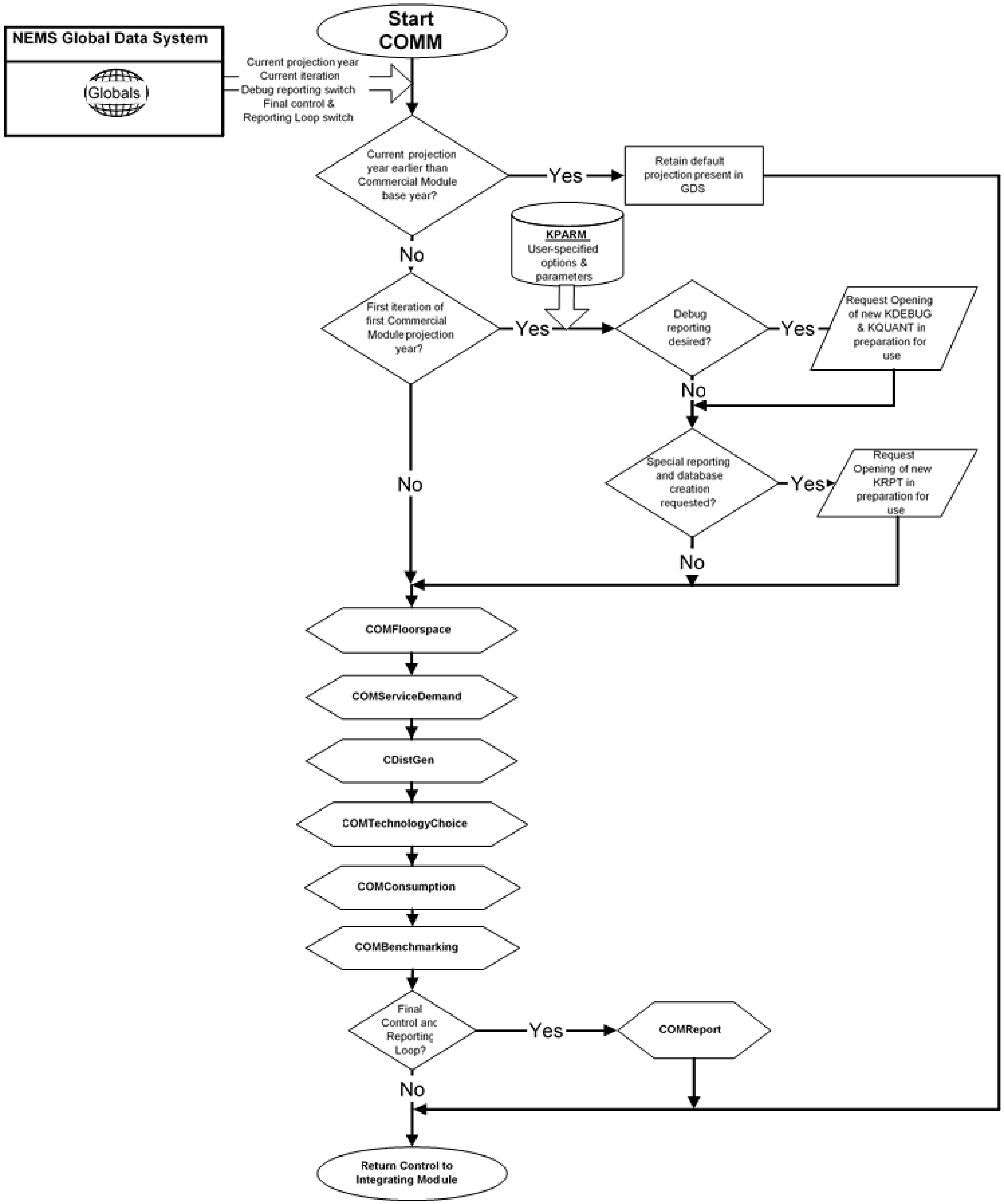


Figure 4. COMFloorspace calculation process flow

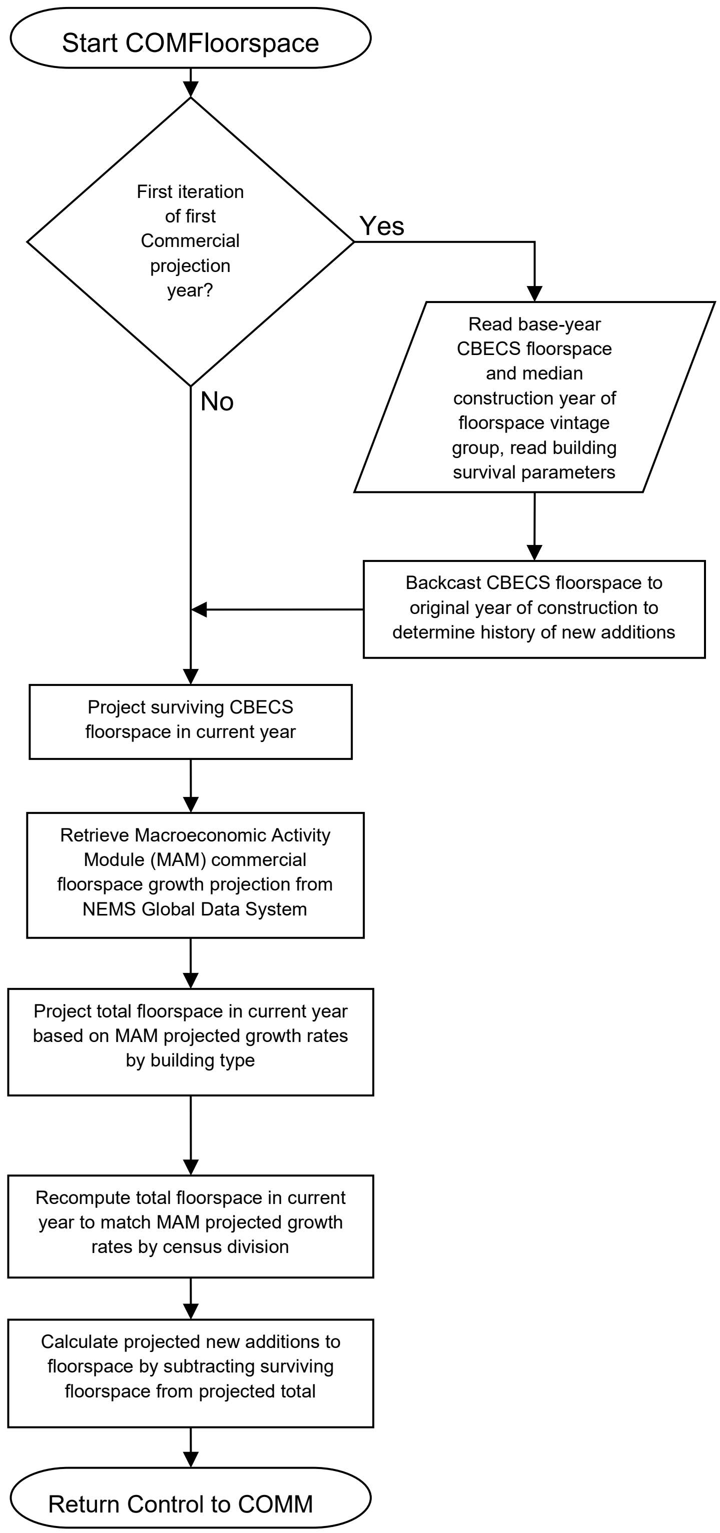


Figure 5 illustrates the processing flow within the Service Demand Submodule of the module, COMServiceDemand. The surviving and new floorspace results generated by the Floorspace Submodule are accepted as inputs by the Service Demand Submodule, along with additional inputs such as base-year EUIs, projected office equipment market penetration, base-year equipment market shares and stock efficiencies, equipment survival assumptions, building shell efficiencies, weather data, and district energy services information. The Service Demand Submodule projects demands for the 10 modeled end uses in each of the 11 building types and nine census divisions separately for newly-constructed commercial floorspace, surviving floorspace with unsatisfied service demands as a result of equipment failure, and surviving floorspace with currently functioning equipment.

Figure 6 illustrates the processing flow within the Distributed Generation and CHP Submodule of the module, CDistGen. The Distributed Generation and CHP Submodule requires technology-specific inputs and financing parameters, along with additional inputs such as historical commercial CHP data, projected program-driven market penetration, and fuel prices. The Distributed Generation and CHP Submodule projects electricity generation, fuel consumption, and water and space heating supplied by DG and CHP technologies. Penetration of these technologies is based on how quickly an investment in a technology is estimated to recoup its flow of costs.

Figure 7 illustrates the processing flow within the Technology Choice Submodule, COMTechnologyChoice. The Technology Choice Submodule requires a variety of inputs, including service demands produced by the Service Demand Submodule; equipment-specific inputs, consumer behavior characterization, and risk-adjusted time preference segmentation information specific to the CDM; and NEMSNEMS outputs including Treasury note rates from the MAM and fuel prices from the EMM, NGMM, and LFMM. The result of processing by this submodule is a projection of equipment market shares of specific technologies retained or purchased for servicing new floorspace, replacing failed equipment, or retaining existing/retrofitting economically obsolete equipment. This submodule also calculates the corresponding fuel shares and average equipment efficiencies by end-use service and other characteristics.

Figure 8 illustrates the processing flow within the Consumption Submodule, COMConsumption. The average equipment efficiency and fuel proportions output by the Technology Choice Submodule are combined with the projected service demands generated by the Service Demand Submodule to produce the projection of major fuel consumption by building type, census division, and end use. We incorporate several additional considerations into the final projection, including accounting for the fuel used for electricity generation and CHP in commercial buildings and fuel consumption for the purposes of providing district energy services. This submodule also projects demands for the five minor fuels using log-log regression equations based on historical census division-level consumption, floorspace, and pricing data. Figure 9 illustrates the Benchmarking Submodule of the fuel consumption projection, COMBenchmarking. Data input from the State Energy Data System (SEDS) and (if the user chooses) fuel consumption projections produced for the *Short-Term Energy Outlook* (STEO) are compared with the basic CDM fuel consumption projection during the period of time over which they overlap in an attempt to calculate energy consumption in the commercial sector not attributable to the building end uses explicitly modeled in the CDM. The difference between the basic CDM fuel consumption projection and the fuel consumption given by the SEDS or STEO is attributed to non-building energy use and referred to as a *mistie*. If desired, the calculated non-building consumption is evolved in one of several methods chosen by the user and added to the basic CDM projection.

Figure 5. COMServiceDemand calculation process flow

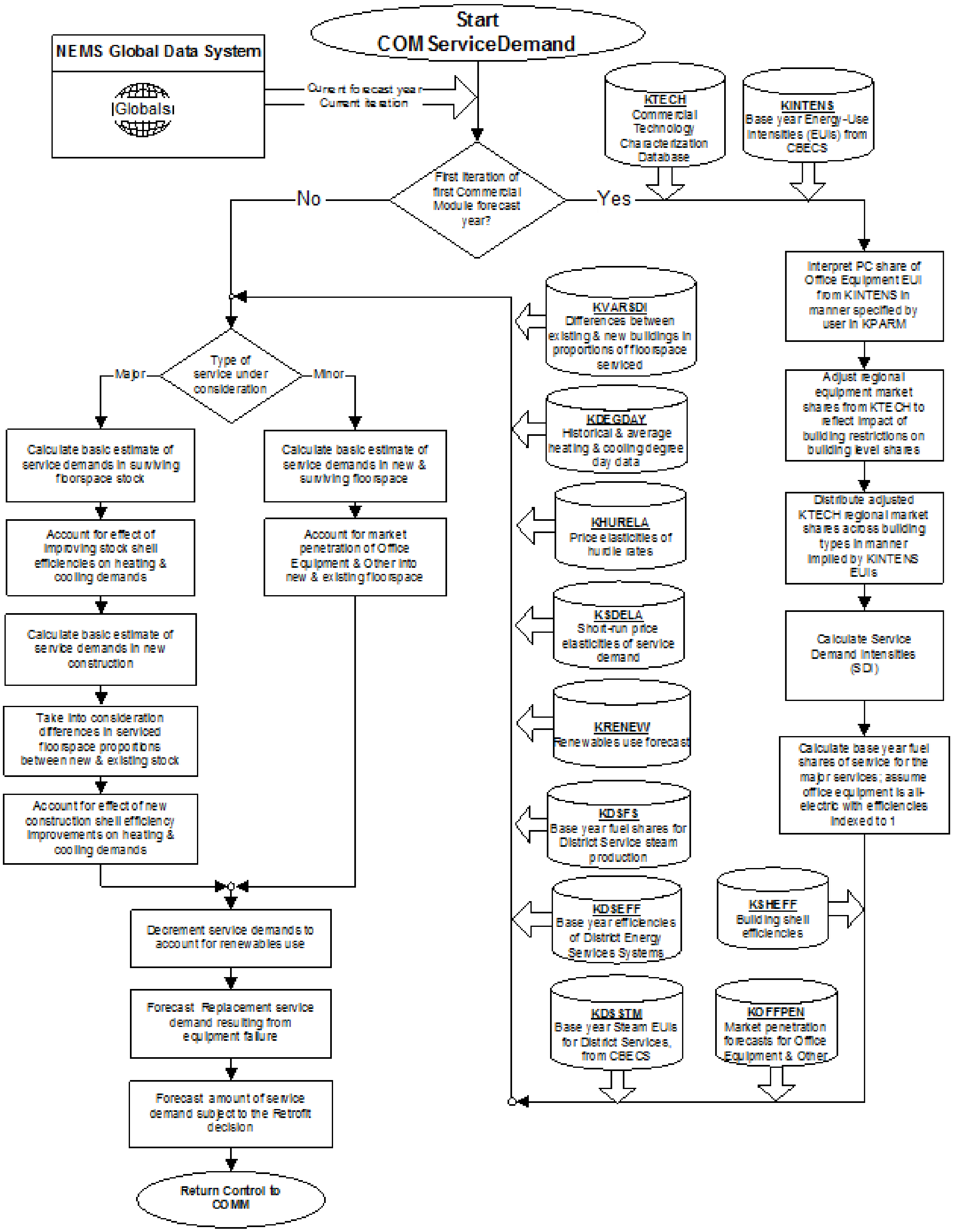


Figure 6. CDistGen calculation process flow

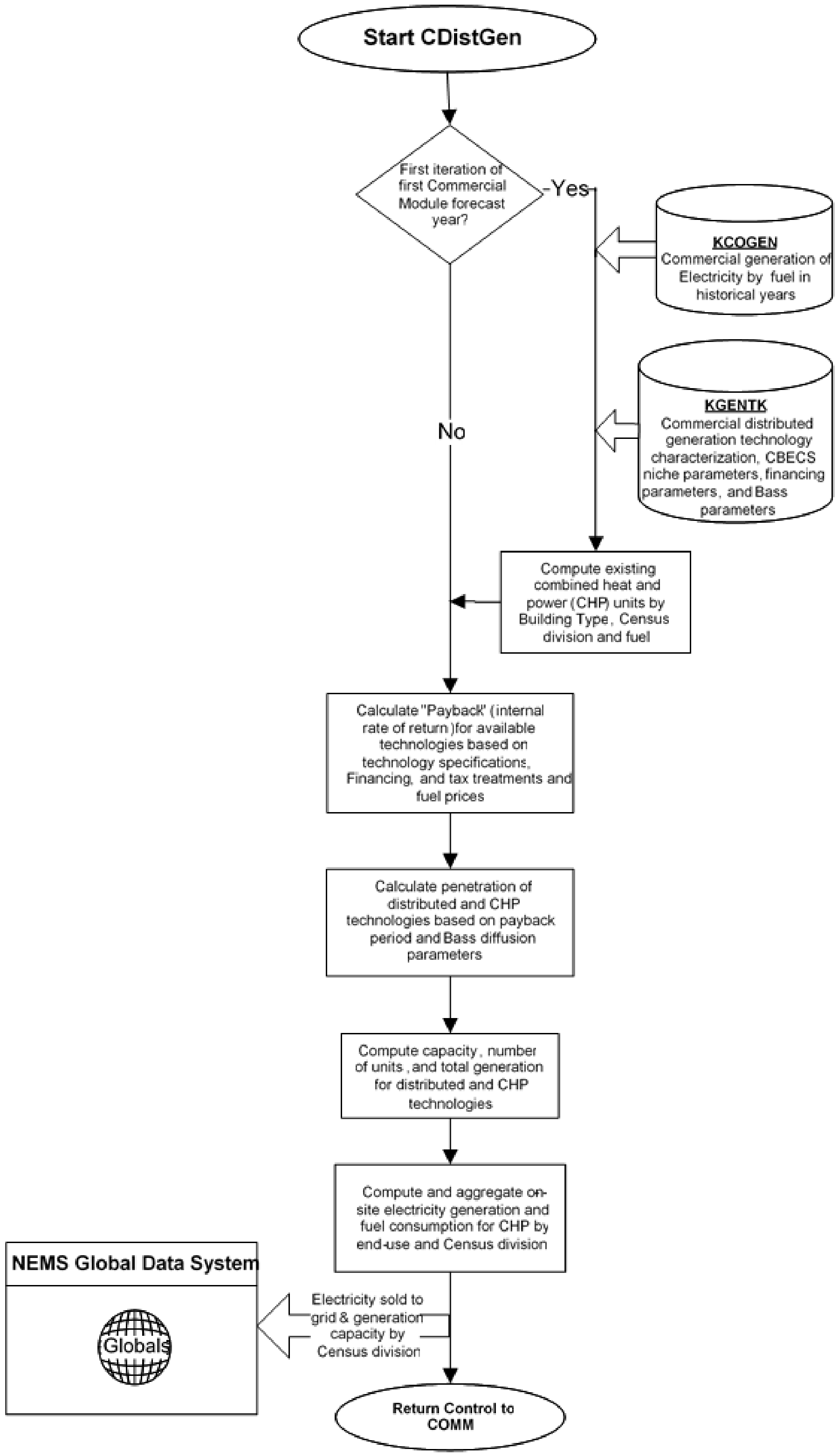


Figure 7. COMTechnologyChoice calculation process flow

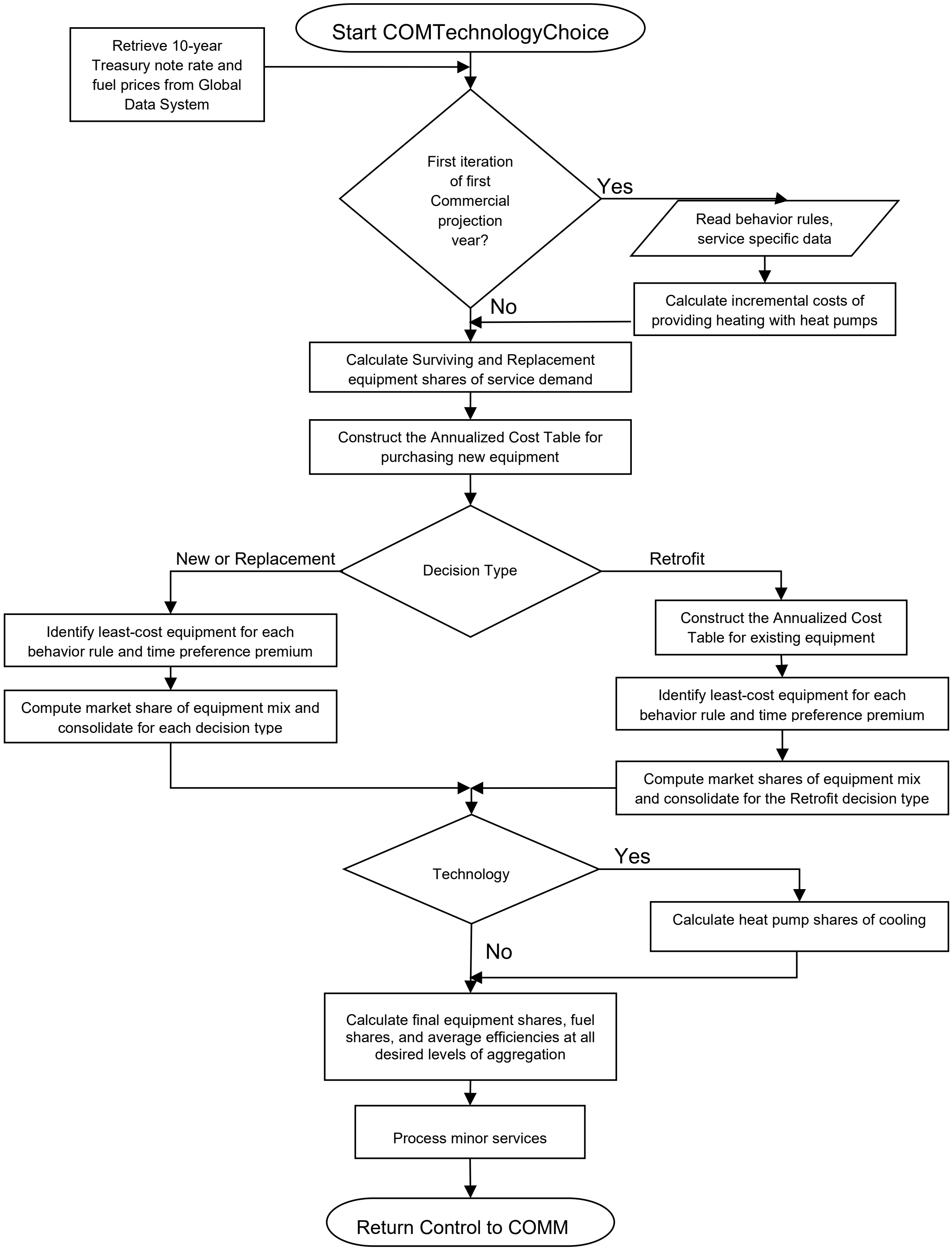


Figure 8. COMConsumption calculation process flow

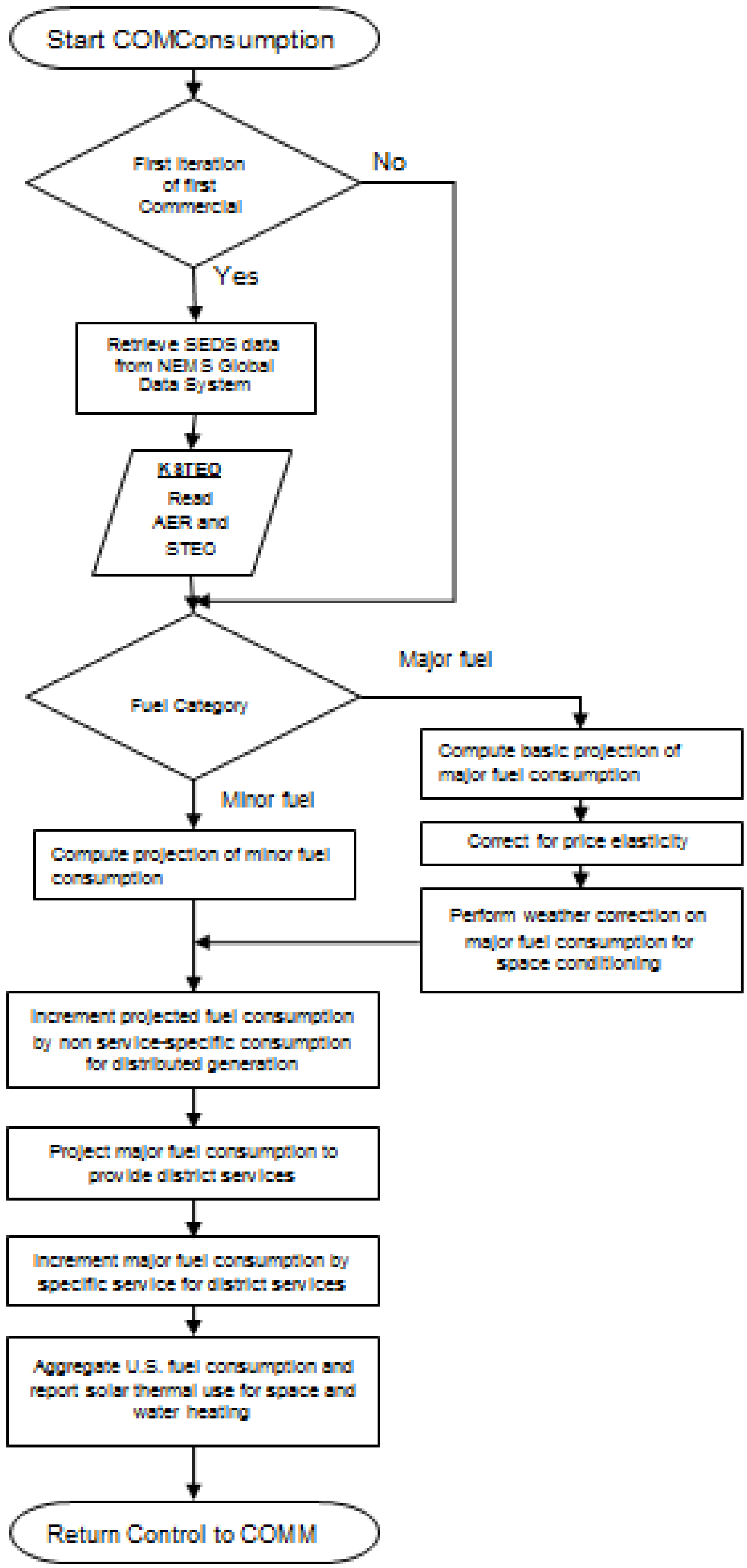
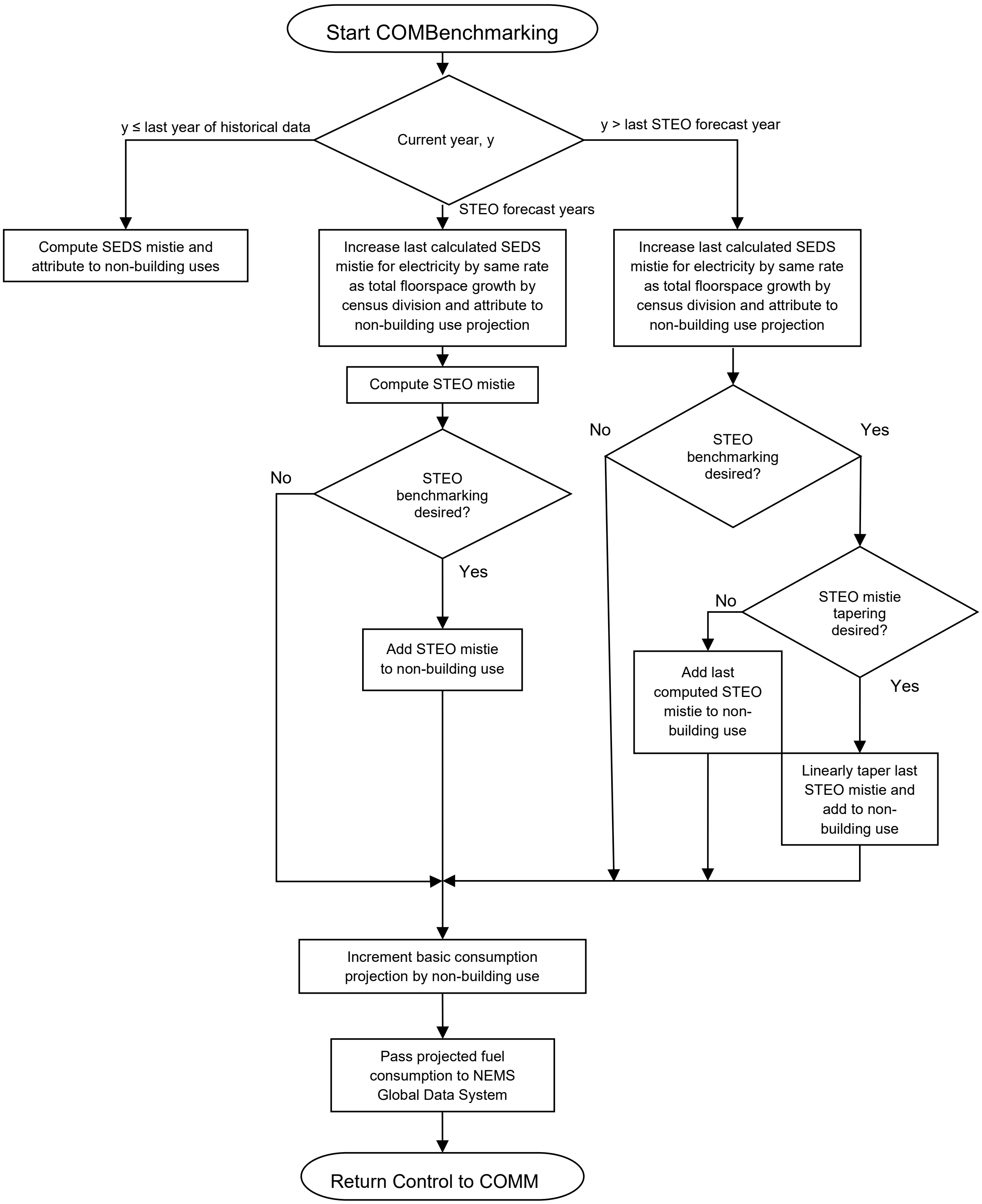


Figure 9. COMBenchmarking calculation process flow



A final reporting subroutine, COMReport, generates detailed documentation on the Final Control and Reporting Loop of the last projection year. The module handles numerous subcategories and additional considerations for each of the broad process categories given above. These subcategories and considerations are described, with references to the appropriate equations in Appendix B, in the Key Computations and Equations section of Chapter 4 under the headings of the applicable subroutines.

Key computations and equations

This section provides detailed solution algorithms arranged by sequential submodule as executed in the NEMS CDM. General forms of the fundamental equations involved in the key computations are presented, followed by discussion of the numerous details considered by the full forms of the equations provided in Appendix B.

Floorspace Submodule

The Floorspace Submodule uses the census-division-level, building-specific total floorspace growth rate projection from the MAM as its primary driver. Many of the parameter estimates used in the CDM, including base-year commercial sector floorspace, are developed from the CBECS database. Projected total commercial floorspace growth is provided by the MAM through the MC_COMMFLSP member of the NEMS Global Data Structure (GDS).[12] Commercial floorspace growth from the MAM is specified by the 13 building categories of the database of historical floorspace estimates developed by McGraw-Hill Construction, indexed to the CDM base year, and projected at the census-division level based on population, macroeconomic drivers, and historical time trends. To distinguish the CDM floorspace projection ultimately produced within the CDM from that provided by the MAM, the latter is referred to as the MAM floorspace growth projection in this report.

The Floorspace Submodule first backcasts the CBECS floorspace stock to its original construction years and then simulates building retirements by convolving the time series of new construction with a logistic decay function. New floorspace construction during the projection period increases according to MAM projected growth rates. If the new additions computations produce a negative value for a specific building type, new additions are set to zero.

The building retirement function used in the Floorspace Submodule depends on the values of two user inputs: average building lifetime and gamma. The average building lifetime refers to the median expected lifetime of buildings of a certain type; that is, the period of time after construction when half of the buildings have retired and half still survive. The gamma parameter, γ, corresponds to the rate at which buildings retire near their median expected lifetime. The proportion of buildings of a certain type built at the same time that are surviving after a given period of time has passed is referred to as the survival rate. The survival rate is modeled by assuming a logistic functional form in the CDM and is given by equation B-1 in Appendix B. This survival function, also referred to as the retirement function, is of the form:

[12] For the methodology used to develop the MAM floorspace projection, please see the corresponding MAM model documentation.

$$Surviving\ Proportion = \frac{1}{(1+\left(\frac{Building\ Age}{Median\ Lifetime}\right)^{\gamma})} \qquad (1)$$

Existing floorspace retires over a longer time period if the median building lifetime is increased or over a shorter time period if the median lifetime is reduced, as depicted in Figure 10 using a constant gamma value of 3.0. Average building lifetimes are positively related to consumption; the longer the average building lifetime, the more slowly new construction with its associated higher-efficiency equipment enters the market, prolonging the use of the lower-efficiency equipment in the surviving stock. This scenario results in a higher level of energy consumption than in the case of accelerated building retirements and the phase-in of new construction.

The user-specified gamma parameter partly determines the shape of the survival rate function that defines the acceleration of the rate of retirement around the average building lifetime. The effects of varying the value of gamma with an assumed median building lifetime of 50 years are illustrated in Figure 11. The larger the value of gamma, the slower the initial rate of retirement and the steeper the survival curve near the median lifetime, which implies that a greater number of buildings will retire at or very near the average lifetime. Large values of gamma should be avoided because they imply that a vintage of buildings will retire almost entirely at its average lifetime. The converse is true as well. Small gamma values will retire floorspace more evenly over the range of lifetimes.

Figure 10. Floorspace survival function sensitivity to median building lifetimes

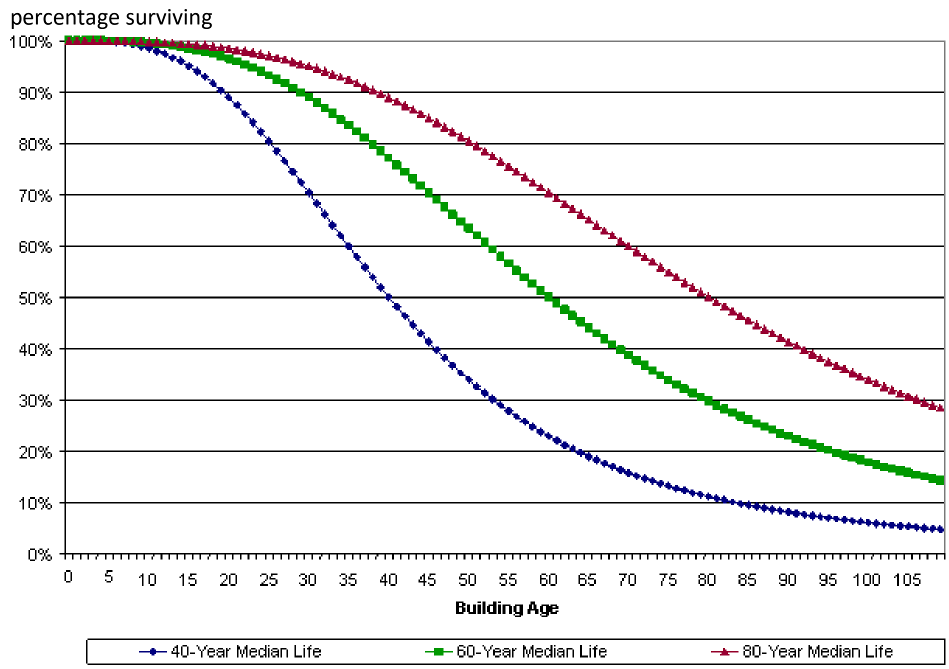
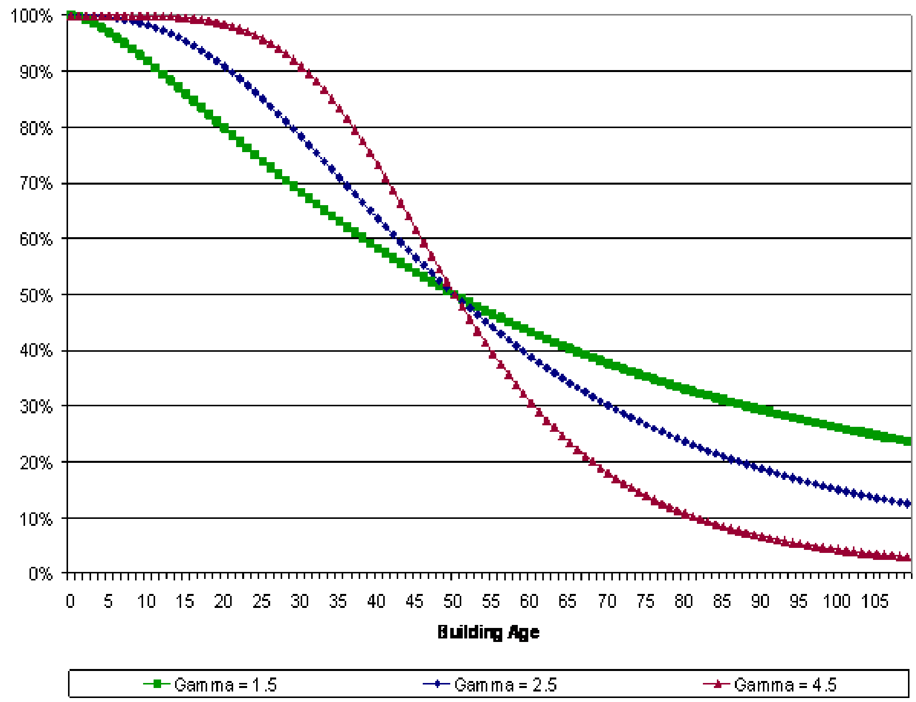


Figure 11. Alternative gamma assumptions and results

percentage surviving



The gamma parameter affects final energy consumption by determining how gradually the floorspace vintage is retired. A large gamma causes nearly the entire vintage to retire within a few years of the average building lifetime, which in turn results in replacement of the retiring floorspace with new construction in an equally uneven manner. Uneven retirement and construction results in rapid escalation of average equipment efficiencies as large amounts of new equipment are rapidly introduced, resulting in an erratic consumption time path.

The NEMS CDM is designed to accept user inputs for gamma and median building lifetime, by building type. This flexibility enables the module to reflect the distinguishing characteristics of the different building types. The median building lifetime and gamma values are assumed to be the same across geographic regions. The gamma values are also assumed to be constant over age and over vintages for each building type. The current values for median building lifetime and gamma, based on analysis of data from the previous five CBECS and other sources referenced in Appendix A, are presented in Table 5.

Table 5. Floorspace survival parameters

Building type	Median building lifetime (years)	Gamma
Assembly	55	1.2
Education	62	1.4
Food sales	55	1.0
Food service	50	1.4
Health care	55	1.4
Lodging	53	1.4
Large office	65	2.0
Small office	58	1.5
Mercantile and services	50	1.3
Warehouse	58	1.3
Other	60	1.3

Surviving floorspace from previous years depends on both the composition of the base-year CBECS stock and all new floorspace added between the base year and the current year of the projection period. In addition, survival characteristics vary among building types. Specifically, to calculate the surviving floorspace in each year, it is necessary to consider the amounts and building types of all floorspace by vintage range, as well as the corresponding survival parameters. These factors are considered in the CDM using the following approach:

1. During the first pass through the algorithm, existing CBECS floorspace by building type, census division, and vintage range is input from file KFLSPC.
2. The median year of construction for each vintage range is input from file KVINT. These values also vary with building type and census division.
3. The key building survival parameters discussed above are input from file KBLDG. These parameters include the median lifetime for each building type and a shape parameter (gamma) that characterizes the shape of the Logistic Building Survival Function used to represent the surviving proportion of original floorspace as a function of time for each building type. Equation B-1 in Appendix B is the mathematical expression of the Logistic Building Survival Function.
4. Based on the building parameters described in step 3, base-year CBECS floorspace is backcast to new floorspace in the original year of construction. Conceptually, this step is simply the inverse of building retirement and is performed using Equation B-2 of Appendix B. Ultimately, if the age of a certain amount of floorspace is known, then the original year of construction and the surviving proportion as given by Equation 1 or B-1 are also known. The relationship of these quantities is given by:

   $$Surviving\ Stock = (Original\ Stock)\ .\ (Surviving\ Proportion) \qquad (\mathbf{2})$$

   Dividing the surviving stock by the surviving proportion gives the original stock in the year of construction. This time series of new floorspace is concatenated with the new floorspace projected for previous years of the projection period (described below) to produce a total history of new additions to floorspace, starting with the original stock of the oldest vintage in CBECS. Surviving floorspace in any given year is then calculated for each building type by using the appropriate survival parameters to determine the proportion of original stock that survives from each previous year into the current year of the projection. This calculation is accomplished as shown by Equation B-3 in Appendix B.

To calculate new additions to floorspace in the current projection year, the surviving floorspace calculated above is combined with the total floorspace projection grown using outputs from the Macroeconomic Activity Module of NEMS. The MAM projects annual percentage growth of new floorspace by MAM building type through the end of the projection period. The 12 commercial building types projected in the MAM are amusement, automotive, dormitory, education, health, hotel, miscellaneous, office, public service, religious, store, and warehouse. Because the MAM's source of historical floorspace data does not directly correspond to CBECS building types, MAM floorspace growth is applied either directly to CDM building types or multiple MAM building type growth rates are combined and applied to CDM building types. For example, CDM small office floorspace is grown by a share of MAM office and health care floorspace rates.

We obtain new additions to floorspace for each CBECS building type by subtracting the floorspace projected as surviving into the current year from the total floorspace in the current year, as shown by Equation B-8, completing the projection of new floorspace. Equation B-9 simply prevents negative projections of new additions by replacing such occurrences with zero. Equation B-10 then gives the final value obtained for total floorspace.

This approach is necessary because the floorspace projection read from the MAM is not available as separate projections for new additions and existing floorspace stock.

Service Demand Submodule

As indicated in Table 1, the CDM partitions energy-consuming activities in the commercial sector into 10 services.

Table 6. Energy-consuming services in the commercial sector

Index	Name	Category
1	Space heating	Major
2	Space cooling	
3	Water heating	
4	Ventilation	
5	Cooking	
6	Lighting	
7	Refrigeration	
8	Computing	Minor
9	Office equipment	
10	Other	

The Service Demand Submodule accounts for the delivered energy for each end-use service demanded. The service demand is sensitive to a variety of inputs including base-year energy use intensities (EUIs), base-year efficiencies of equipment, efficiencies of building shells, short-term price elasticities, and weather.[13] Service demands for district energy services and solar thermal space heating are considered separately.

The base-year EUIs represent the average amount of energy required to obtain each service for a defined area. Currently the model uses EUIs developed from the CBECS end-use consumption estimates.[14] The concept that fuel is consumed in commercial buildings to satisfy demands for the services enumerated above is central to the model. Service demand is defined as Btu out (amount of delivered energy). Equipment efficiency (or the equipment Coefficient of Performance [COP]), together with the distribution of equipment and the levels of service demanded, determine the fuel B Btu out to Btu in for a closed system, which is a system that does not draw from external sources for Btu transference. The COP is a more appropriate measure of equipment performance where the system is more open, as in the case of a heat pump. In the case of a heat pump, a small amount of energy is consumed in moving a larger amount of heat between the interior and exterior of a structure, making the COP greater than one, the theoretical maximum value for closed-system efficiency. The terms efficiency and COP are used interchangeably in this report when referring to the ratio of delivered to consumed energy. These terms are also used where either ventilation or lighting is the service, although the actual measure used in the model for ventilation is cubic feet per minute of ventilation air delivered to Btu in, and for lighting the actual measure is efficacy, defined as lumens delivered per watt of electricity consumed.

Service demand intensity (SDI), defined as the demand for a service per square foot of floorspace, varies with service, building type, and location, but we assume it remains constant for each service, building type, and location. The service demand obtained by multiplication of the SDI with the floorspace is, however, subject to modification by various factors such as shell efficiency load factors for heating and cooling and fuel price elasticity as described below.

We compute the SDI for the major services by applying the composite average equipment efficiency for the service to the EUI. This calculation provides a more realistic picture of the energy needed to provide an end-use service because energy losses occur during conversion to a consumable service. The base-year EUI for each service is related to the SDI and the average efficiency of the base-year equipment mix as follows:

$$SDI\left(\frac{Btu\ out}{ft^2}\right) = EUI\left(\frac{Btu\ in}{ft^2}\right).COP_{average} \qquad (\mathbf{3})$$

The actual calculation of SDI in the model involves several additional considerations, such as buildings from which specific equipment is restricted, base-year equipment market shares, and the distribution of

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[13] Impacts on service demands as a result of price elasticity, weather, and the rebound effect are calculated by the End-Use Consumption Submodule, based on the direct proportionality between fuel consumption and service demand. This is necessary because the fuel shares of provided service are not known until after the selection of the equipment mix by the Technology Choice Submodule.

[14] U.S. Energy Information Administration. *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files. Washington, DC, December 2022. A description of the estimation process is given under Technical Information.

census-division level equipment market shares across the different building types. In addition, because the model accommodates fuel switching, the total SDI for the service must be calculated, rather than an SDI corresponding to each fuel used in the base year. The basic calculation illustrated by Equation 3 is carried out by evaluation of Equations B-11 through B-18 in Appendix B for each major service.

We model minor services (computing, office equipment, and MELs) in less detail than the major services. In particular, specific discrete minor service technologies are not characterized within the CDM; instead, the efficiency of the composite mix of technologies for each minor service is modeled as evolving relative to its base-year level. The actual base-year average efficiency of the minor service equipment mix is indexed to equal one, resulting in the minor service SDI and EUI values being equal, as indicated by Equation B-17.

The basic computation of service demand for each service and category of floorspace (new or surviving) is the same for major and minor services:

$$Service\ Demand(Btu\ out) = SDI\ \left(\frac{Btu\ out}{ft^2}\right) \cdot Floorspace\ (ft^2) \qquad (4)$$

The computation illustrated above is accomplished by evaluating Equations B-25, B-34, and B-35.

Building shell efficiencies for new construction are user inputs in the form of shell heating and cooling load factors that can be modified to generate scenarios to reflect a variety of technologies and policy options such as increased insulation, weather-stripping, or new highly energy-efficient construction materials. These load factors represent the impacts of building shell efficiency improvements on service demand and are based on a parametric study completed for EIA by ICF International.[15]

The model accounts for building shell improvements due to commercial building code adoption and compliance. We updated heating and cooling load factors, which represent the thermal envelope properties for both newly constructed and existing buildings relative to the existing base-year building stock. Shell efficiencies are indexed to the average base year values by building type and census division. Each year, the overall average shell efficiency of commercial buildings increases incrementally as newer, more efficient buildings are added to the commercial building stock.

Over the projection period, existing building shells are assumed to improve relative to base year commercial building stock efficiency, but less quickly than new building shells. The model uses shell efficiency factors that increase to user-specified values input for 2018, 2020, 2030, 2040, and 2050. The model interpolates load factors between these years. The level of shell improvement is affected by:

- Current building practices
- Rates of adoption for building codes
- Research, development, and deployment programs focusing on shell improvements
- The long-lived nature of commercial buildings

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[15]ICF International, L.L.C., *Development of Commercial Building Shell Heating and Cooling Load Factors*; prepared for EIA January 22, 2018.

Additional improvement is assumed for new construction to account for adoption of the ASHRAE 90.1-2007, ASHRAE 90.1-2010, ASHRAE 90.1-2013, and AHSRAE 90.1-2016 standards for building shell measures. Based on provisions in the American Recovery and Reinvestment Act of 2009 (ARRA09), states are assumed to adopt and enforce the 2007 standard by 2018. Information from a study by the DOE Building Energy Codes Program[16] shows faster adoption of the code by commercial buildings and noticeable adoption of the 2013 standard. Full adoption of the 2007 standard is assumed by 2016 with full adoption of the 2013 version of the code by 2022. Changing shell efficiencies affect space heating and space cooling service demands as follows:

$$Service\ Demand = (Service\ Demand\ with\ base\ year\ shell) * (ShellFactor) \qquad (5)$$

with the appropriate load factor (heating or cooling) used for each end-use service. The calculations involved in computing the appropriate shell load factors and evaluating the expression illustrated by Equation 5 are accomplished using Equations B-21 through B-24, Equation B-26 through Equation B-29.

The computation of service demand for space cooling, ventilation, and MELs is adjusted to account for the requirements of data centers that house large numbers of data center servers and related equipment, including uninterruptible power supplies. For AEO2025, data centers are included in all commercial building types with data center server rooms present ("on-premise data centers") according to the 2018 CBECS. The proportion of on-premise data center floorspace is given by Equation B-30. The adjustment to account for increased service requirements is shown in Equations B-31 and B-32. Projections of data center floorspace as a share of most building types and estimates of additional consumption for cooling, ventilation, and MELs are developed based on the literature referenced in Appendix A. Projections for computers, including servers, and other office equipment used in data centers are included in the *computing* and *office equipment* end-use services.

The CBECS data indicate that a greater proportion of the floorspace is lit, heated, and cooled in buildings constructed after 1989 than in older buildings. The effect of these service demand differences between newer and older buildings has been estimated and is accounted for using Equation B-33.

Although the market for major services is generally assumed to be saturated, additional penetration of the minor services of computing, office equipment, and MELs is modeled. Projections of continuing market penetration are prepared offline for office equipment and the non-specific portion of MELs as described in Appendix A and incorporated into the service demand projection for these minor services using Equations B-36 and B-39.

Service demand projections, including continuing market penetration, for several specific categories of electricity use within MELs are based on electricity consumption estimates and projected national-level trends from multiple reports. The specific categories modeled and their corresponding category indexes are provided in Table 7.

Growth rates for electricity use in these categories are governed by the specific market segments served, by technology advances, and by minimum efficiency standards, if applicable. For example,

[16] Pacific Northwest National Laboratory, *Building Energy Codes Program: National Benefits Assessment, 1992-2040*, prepared for U.S. Department of Energy, March 2014.

technology advances and growth in health care services affect projections for electricity use by medical imaging equipment. Future electricity use by dry-type distribution transformers is affected by growth in electricity demand and by the efficiency standards included in EPACT05.

The computation of service demand for the specific categories of MELs, except for municipal water services, is carried out by evaluating Equations B-42 to B-47. Projected electricity use for municipal water and telecom services is calculated as part of non-building energy consumption as illustrated in equations B-136 through B-140.

Table 7. Miscellaneous electric load use categories

Miscellaneous category index (mc)	Electricity use
1	Distribution transformers: dry-type
2	Kitchen ventilation
3	Security systems
4	Laboratory refrigerators and freezers
5	Medical imaging equipment: MRI, CT Scan, X-Ray, and Ultrasound
6	Large format video boards
7	Coffee brewers
8	Non-road electric vehicles: lift trucks, forklifts, golf carts, and floor burnishers
9	Fume hoods
10	Laundry: washers, dryers, and dry cleaning equipment
11	Elevators
12	Escalators
13	IT equipment
14	Uninterruptible power supplies: non-data centers
15	Uninterruptible power supplies: data centers
16	Shredders
17	Private branch exchange
18	Voice over IP
19	Point-of-sale systems (PoS)
20	Warehouse robots
21	Televisions

We compute the portion of service demand satisfied by solar water heaters endogenously as solar water heating technologies are included in the Technology Choice Submodule. However, we compute the portion of service demand satisfied by solar space heating and daylighting using exogenous projections for renewable energy for the commercial sector as described in the Appendix A description for the SolarRenewableContrib variable. The penetration of solar energy changes the amount of service demand, affecting the end-use consumption for the major services. The incorporation of solar services in this manner provides a useful method for policy analysis. By varying adoption of these technologies in response to policy mandates or incentive programs, we can determine the effects on consumption of conventional fuels. Equations B-48 and B-49 perform the calculations involved in modeling the penetration of solar services.

The short-term price elasticity of demand is currently provided for all end-use services. The parameters included in the CDM are currently set to -0.25 for all major services except refrigeration, which is set to -0.10. A value of -0.05 is currently used for all types of office equipment and electric MELs. These values are representative of estimates provided in the literature as referenced in Table A-5.

The elasticity parameters represent the short-term price responsiveness of service demands in the model. The values for the elasticities must necessarily be non-positive because the services are assumed to be normal goods, meaning that, as fuel prices increase, the quantity of energy services demanded declines. The full elasticity effect is graduated over a three-year period to allow the degree of consumer response to vary with significant changes in fuel prices. To capture the effect of fuel price changes on demands for services satisfied by equipment using the affected fuel, the service demand elasticity calculation is postponed until after the final determination of the current year equipment mix as calculated by the Technology Choice Submodule. Because of the linear relationship between service demand and fuel consumption, as illustrated in Equation 3 above, a proportional change in service demand results in the same proportional change in fuel consumption. The calculation of the service demand elasticity effect for each year is shown in Equation B-110. The service demand elasticity application is illustrated by Equation B-111. Equation B-111 also illustrates the modification of pure price elasticity to account for the fact that improving equipment and shell efficiencies reduces the actual cost of meeting certain service demands. Incorporation of this *take-back* or *rebound* effect, as well as weather corrections (described in the End-Use Consumption Submodule section), is also postponed until the calculation of fuel consumption.

By contrast, long-term responses to energy prices are determined endogenously through potentially altered equipment choices. Installed equipment costs, equipment and building shell efficiencies, energy prices, hurdle rates, and annual equipment utilization rates all interact to affect demand and determine long-term energy price responses. *Behavioral Economics Applied to Energy Demand Analysis: A Foundation* provides a thorough discussion of both short-term and long-term price response in the CDM.

The final purpose of the Service Demand Submodule is to determine the amount of service demand in surviving floorspace that becomes unsatisfied in the current projection year as a result of equipment failure. Equipment is retired based on a simplified vintaging scheme, where each year a proportion of each type of equipment fails, with the proportion given by the reciprocal of the expected equipment lifetime expressed in years. Thus, if the expected lifetime for a particular piece of equipment were 10 years, the CDM would assume that each year one-tenth of the total amount of that equipment fails. This relationship is used to split the total amount of service demand in surviving floorspace into the portion in need of equipment replacement and into the surviving portion, for satisfaction by appropriate decisions in the Technology Choice Submodule. The calculation of this split is performed by Equations B-55 to B-58.

Distributed Generation and Combined Heat and Power (CHP) Submodule

The Distributed Generation and CHP Submodule (subroutine CDistGen) projects electricity generation, fuel consumption, and water and space heating supplied by 11 distributed generation technologies. The characterized technologies include photovoltaics, natural gas (fuel cells, reciprocating engines, turbines, and microturbines), diesel engines, coal-fired CHP, biomass generation including municipal solid waste and wood generators, hydroelectric, and distributed wind turbines.[17] However, technologies with high emissions profiles like coal and diesel will generally be subject to environmental constraints and as such are not expected to grow significantly over the projection period. Thus, we assume that new penetration for these technologies will be limited.

We develop estimates of CHP electricity generation for historical years by technology, census division, and building type from data contained in the most recent year's version of the Form EIA-860 Database, *Annual Electric Generator Report*. Fuel types are first mapped to appropriate generating technologies. Next, an estimate of the number of buildings incorporating each technology is developed based on total generated electricity (from Form 860) divided by the average generation of electricity for the particular technology to which the fuel type was mapped. Equations B-161, B-163, and B-164 calculate annual generation from distributed technologies, in kilowatt-hours. The estimated units then form the installed base of CHP equipment that is carried forward into future years and supplemented with any projected additions. Energy consumption and usable waste heat (used first for water heating and then for space heating if sufficient amounts are generated) are computed based on technology characteristics (Equations B-167 and B-168).

For projection years, distributed generation technology penetration rates are estimated by census division, building type, building size category, and solar/energy price niches, and they vary depending on floorspace vintage (newly constructed versus existing floorspace). We assume that the maximum possible cumulative penetration value for a given technology is a function of how quickly an investment in a technology is estimated to recoup its flow of costs based on the internal rate of return (IRR) computed from a cash-flow model—in other words, the number of years required to achieve investment *payback*. Payback years are computed based on compounded returns (using the IRR). In addition to the value of energy savings, the NEMS distributed generation submodule includes business tax effects (both timing and magnitude) in the cash flow calculations, thus allowing the modeling of alternative tax policies. In many cases, the investment may not achieve a positive IRR, so the number of payback years is set to 30. In general, as the economic returns improve, the IRR increases and the payback period is shortened, increasing the projected penetration. Maximum possible penetration is assumed to never exceed 90%, even with payback less than one year. The equation estimating maximum possible penetration (M) is:

$$M = \frac{\alpha}{Simple\ Payback} \qquad (5)$$

[17] Assumed technology characterizations for natural gas-fired and oil-fired CHP technologies are based on a report completed for EIA by Leidos (formerly Science Applications International Corporation). See the detailed model inputs in Appendix A for full citation.

Because the IRR approach captures the impacts of the timing of financial outlays and benefits, it gives greater weight to tax credits and other incentives, which are generally received near the beginning of the cash flow horizon. The working assumption is that for new construction, investment in distributed generation technologies is combined with the building costs and financed along with the building. These financing assumptions are supplied in the generation technology input file (kgentk.txt).

For each potential investment decision, a cash-flow analysis covering 30 years, from the date of investment, is made (see Equations B-148 through B-179 for details). The calculations include the costs (down payments, loan payments, maintenance costs, and fuel costs) and returns (tax deductions for expenses and depreciation, tax credits, and energy cost savings) from the investment. In any particular year, the net of costs and returns can either be positive or negative. The financing assumptions assume that the down payment component of the purchase cost occurs before the investment is fully up and running. Investment returns begin in year two as well as any associated tax credits. Once the 30-year analysis is complete, the number of payback years is developed based on the IRR, which in turn drives projected penetration into newly constructed floorspace.

The allowed depreciation treatment for distributed generation technologies can also play an important role in determining penetration rates. Depreciation allowances in NEMS represent initial costs, including material and labor installation costs, divided by the tax life of the equipment. Current tax regulation provides that DG technologies other than solar photovoltaics and distributed wind turbines be depreciated using the straight-line depreciation method. To facilitate the modeling of potential alternative tax depreciation treatments, the CDM allows the user to select a depreciation method via the kgentk.txt file. The user selects between the straight-line depreciation method and the accelerated depreciation method (in other words, the declining balance method) by providing an input for each projection year. A value of 100% indicates straight-line depreciation while a value of 200% indicates the double-declining method (intermediate values are also allowed such as 150% declining balances, etc.). Current business tax treatment for building-related investments specifies straight-line depreciation and a tax life of 39.5 years according to the Internal Revenue Service. Exceptions have been codified in current tax law for photovoltaic and distributed wind technologies, which are allowed to be depreciated under a Modified Accelerated Cost Recovery System classification using a five-year tax life and 200% declining balance depreciation. The depreciation calculation is provided in Equations B-159 through B-161.

A Bass Diffusion Model (BDM), estimated based on a regression against historical data, projects the speed at which technology diffusion asymptotically approaches the maximum penetration (*m*) as well as the proportion of the maximum possible penetration (*m/M*) that the technology eventually achieves. Several studies have tested the BDM for fit against solar PV data and found a strong empirical relationship (Packey, 1993; Evans, 2005; Agrawal, 2015; Wang, et. al., 2017). The BDM uses two parameters—*p,* the coefficient of innovation, and *q*, the coefficient of imitation—to determine the shape of product penetration over time, according to the following equation:

$$\frac{\boldsymbol{f(t)}}{\boldsymbol{1 - F(t)}} = \boldsymbol{p + qF(t)} \tag{6}$$

where *F(t)* represents cumulative adoption as a percentage of the market maximum at time *t,* and *f(t)* represents the adoption rate, or $\frac{dF(t)}{dt}$. The Bass equation produces an *s*-shaped penetration curve, with *F(t)* asymptotically approaching 1 as *t* approaches infinity. A third parameter, *m,* represents final market potential for the product. To determine the size of the market at time *t*, *m* is multiplied by *F(t)*.

A nonlinear least squares (NLS) regression against historical installation data over time is used to estimate *p* and *q* parameters. We obtain historical capacity data for large-scale CHP technologies by census division from Form EIA-860. Other technology capacity data come from third-party sources including:

- The Solar Energy Industry Association (SEIA) Solar Market Insight and Interstate Renewable Energy Council (IREC) Annual Trends Reports for solar PV
- Fuel Cell 2000, ICF's CHP Database, and the U.S. Department of Energy's Fuel Cell Market Reports for fuel cells and microturbines
- The American Wind Energy Association's Small Wind Turbine Global Market Reports for wind

Separate *p* and *q* parameters are estimated for each census division to implicitly account for different policy environments and attitudes in different regions. The NLS regression is specified as (Srinivasan and Mason, 1986):

$$\boldsymbol{G(t) = cF(t) = \frac{c(1 - e^{-bt})}{(1 + ae^{-bt})}} \quad (7)$$

where

$a = \frac{q}{p};$

$b = p + q\ ;$

$c = \frac{m}{M}$, or the probability of eventually adopting the technology; and

M = total number of possible adopters. *M* is calculated as an inverse function of simple payback according to Equation 6, while *m* was determined through the NLS regression.

The technology- and census division-specific Bass diffusion parameters obtained through the NLS regression are supplied in the generation technology input file as described in Appendix A.

Penetration is also affected by consideration of rules, regulations, and policies that affect utility-grid interconnection of distributed generation. State-level scores ranging from zero (closed to interconnection) to one (open to interconnection) are developed to reflect the presence of policies affecting distributed generation. The scores are based on information from the Database of State Incentives for Renewables & Efficiency (DSIRE)[18] and on updates on state legislative and Public Utility Commission websites. Components include state-level renewable portfolio standards (RPS) or goals;

[18] Database of State Incentives for Renewables & Efficiency (DSIRE), Raleigh, NC, accessed August 2024.

public benefit funds that support renewable resources; the existence of net-metering and interconnection standards and rules; whether fuel cells or CHP are eligible RPS technologies; and the existence of solar or wind access laws. We aggregate state-level scores to the census-division level based on population to produce interconnection limitation factors that reduce the penetration resulting from the cash-flow analysis. Interconnection limitations are assumed to decrease over time, ceasing by the end of the projection period. The easing of interconnection limitations over time is presented in Equation B-180 and the effect on penetration is included in Equation B-181.

Economic returns and therefore penetration rates are also potentially affected by learning cost effects modeled for the emerging DG technologies and for microturbines, where costs are expected to decline as further experience is gained in developing these scaled-down gas turbines. Learning effects reduce projected installed costs over time as a technology gains *experience* based on higher cumulative shipments. Such effects are often also referred to as stemming from *learning-by-doing*.[19] Currently, learning effects are included for four distributed generation technologies: photovoltaics, fuel cells, microturbines, and distributed wind generators.

Operationally, distributed generation technology costs for emerging technologies are represented as the minimum of 1) the menu cost read in from the DG technology input file and 2) the endogenous cost that incorporates learning effects (Equation B-148). The endogenous learning cost is based on an inverse relationship between installed cost and cumulative shipments. Thus, the modeled installed cost can be lower than the input menu cost depending on the magnitude of cumulative shipments (which are in turn driven by technology penetration rates) and the learning cost parameters. The learning cost function is driven by cumulative shipments and includes two parameters, alpha and beta. Alpha represents the first-of-a-kind unit cost, and beta is the learning parameter that determines the sensitivity of cost changes to cumulative shipments. Because first-of-a-kind unit costs are generally unobservable, the learning functions calculate a value for first unit cost that calibrates to the current installed costs for the technology given current cumulative shipments and the assumed value of beta.

The calibrated first cost estimates are given in Table 8 along with the learning parameters. The larger the learning parameter, the greater the cost declines for each percentage increase in cumulative shipments. The values for these beta learning parameters were set based on related research for other equipment types and on the vintaging assumptions that apply to grid-based power generation technologies in NEMS. For example, Dutton and Thomas (1984)[20] found parameters in the range of those parameters used for the commercial distributed generation technologies to be among the more common values reported in 22 empirical studies covering 108 types of equipment. The parameter for microturbines was assumed to yield smaller cost declines than for photovoltaics and fuel cells because that technology is already the least expensive and is similar to natural gas turbine technology that is much more commercially mature than any of the three emerging technologies represented. The learning parameter

[19] For a review of the literature on learning costs as well as empirical results for buildings equipment see Richard G. Newell, *Incorporation of Technological Learning into NEMS Buildings Modules*, U.S. Energy Information Administration, Washington, DC, September 29, 2000.
20 Dutton, J. M. and A. Thomas, Treating Progress Functions as a Managerial Opportunity, Academy of Management Review, 1984, Vol. 9, No. 2, pp. 235–247.

for distributed wind turbines is also set to a smaller value, primarily as a result of uncertainty about opportunities for future cost declines in the tower/turbine unit.

Table 8. Distributed generation technology learning function parameters

Technology	Calibrated first cost per kilowatt (alpha)	Learning parameter (beta)
Photovoltaic systems (PV)	$29,665	0.2
Fuel cells	$14,075	0.2
Distributed wind turbines	$6,780	0.05
Microturbines	$4,365	0.15

The primary impact of projected increases in DG technologies for the overall NEMS projections is reduced purchases of electricity from the electricity supply module of NEMS. If the investment is photovoltaic or distributed wind, renewable energy offsets fuel input required by the electric power sector to produce grid electricity because these grid-based renewables have low variable costs (because they do not consume fuel) and will generally be dispatched to the fullest extent, once installed. Thus, for the two renewable technologies, enhanced penetration always lowers the NEMS projection for primary energy consumption. If the distributed technology is a fuel cell or other fuel-consuming technology, electric power sector fuel input is replaced by commercial fuel consumption (primarily natural gas). Fuel-consuming distributed technologies also generate waste heat, which is assumed to be partially captured and used to offset commercial energy purchases for water heating and space heating. Even though the fuel-fired DG technologies are generally less efficient than electric power sector technologies that provide grid electricity, increased penetration of fuel-consuming distributed technologies still typically reduces the overall NEMS projection for primary energy consumption because of the capture and use of waste heat at the distributed generation site.

Technology Choice Submodule

The Technology Choice Submodule models the economic decision-making process by which commercial agents choose equipment to meet their end-use demands. The NEMS CDM represents the heterogeneity of commercial decision agents using three behavior rules and seven distinct risk-adjusted time preference premium categories. This type of consumer or implied market segmentation incorporates the notion that decision agents may consider a variety of parameters in the optimization within the commercial sector. Some participants may display specific behavior as a result of existing biases regarding certain equipment types or fuels. In addition, the distribution of risk-adjusted time preference premiums represents a variety of commercial agents' attitudes about the desirability of current versus future expenditures with regard to capital, O&M, and fuel costs. The flexibility of this representational structure allows the module to be calibrated to historical data even if the causal mechanisms determining demand are not fully understood or formally represented within the model structure.[21]

[21] For further discussion of behavioral factors and their representation in NEMS, see the proceedings of EIA's 2013 Technical Workshop on Behavioral Economics.

Each one of the above market segments is faced by one of three decisions: 1) to purchase new equipment for new buildings, 2) to purchase replacement equipment for retiring equipment in existing buildings, or 3) to purchase retrofit equipment or retain existing equipment for existing buildings. Within each market segment, the commercial agent will search the available technology menu for the least-cost alternative within the constraints of the applicable behavior rule.

Choosing the least-cost alternative within a market segment involves a tradeoff among capital cost, fuel cost, and operating and maintenance (O&M) cost. In the case of renewable energy-consuming equipment, costs may also include the cost of backup equipment. The relative importance of each cost component is a function of consumer risk-adjusted time preference. The NEMS CDM sets all other attributes of a technology constant across choices, and these other attributes do not influence the technology choice decision modeled by the algorithm.

Each technology is modeled to preserve a proportional response between capital, fuel, and O&M inputs and the service output for these technologies. In addition, the technology costs are represented for comparison in such a way that, for a certain total cost, a dollar increase in capital cost must imply more than a dollar decrease in fuel and O&M costs because the dollar spent today toward capital is worth more than any future dollar. Therefore, a tradeoff in the form of further reduction in other costs is necessary to the perceived total cost to remain constant. In addition to this tradeoff, this component allows for optional expectations modeling, in that price expectations can be used to determine the acceptable fuel costs over the expected economic lifetime of the equipment.

We designed the algorithm to choose among a discrete set of available technologies for each decision. The Technology Choice Submodule computes an annualized equipment cost per unit of delivered service as the method of weighting the attributes (capital cost, fuel cost, etc.) and developing a composite score for the technology. Technology choice among the alternatives is made based on the minimum annualized cost per unit of service demand (subject to constraints on the set of potential technologies represented by the behavior rules discussed below). The annualized cost represents the discounted flow of all O&M, capital, and fuel costs of the technology over its lifetime. The discount rate is embedded in this annualized cost through a factor that converts the one-time capital and installation costs into an equivalent annuity of equal annual payments over the equipment lifetime. The basic form of the expression for equipment cost used in the CDM is:

$$\frac{annualized\ cost}{unit\ of\ delivered\ service} = \ (annuitized\ purchase\ \&\ installation\ on\ cost\ component) \qquad (6)$$

$$+ (yearly\ O\ \&\ M\ component) + (expected\ yearly\ fuel\ cost\ component)$$

The unit of delivered service referred to above is thousand British thermal units delivered per hour for all end-use services except lighting and ventilation. The unit of service demand used for lighting is thousand lumens delivered, and for ventilation, it is thousand cubic feet per minute of air delivered. Consideration of the building capacity utilization factor is necessary because, unlike the purchase and installation costs, the yearly O&M and fuel costs will vary depending on the intensity of equipment use.

The CDM contains the option to use a cost function to estimate the unit installed capital cost of equipment as a function of time during the interval of equipment availability, rather than limiting technologies to specific models with constant costs during the model years of availability. The choice to enable the cost trend function is specified through the CDM user parameter CostTrendSwitch. Currently, cost trends represented are of logistic functional form and are separated into three categories corresponding to technology maturity: Infant (emerging or future technologies); Adolescent (existing technologies with significant potential for further market penetration and price decline); and Mature (technologies not expected to decline further in cost). The Adolescent and Infant categories require specification of the initial year of price decline, the year of inflection in the price trajectory, the ultimate price reduction as a proportion of initial cost, and a shape parameter, gamma, governing the rate of price decline. The Mature category corresponds to the previous constant-cost representation. The cost trend function specifications are input through the technology characterization file as described in Appendix A. The cost trend function is enabled in the default mode of model operation, for technologies specified as Adolescent or Infant in any given modeling cycle. As of AEO2025, examples of technologies treated as Adolescent with regard to the cost trend function include select emerging lighting technologies, and a selection of heat pump technologies. Equation B-60 presents the calculation of unit costs using the cost trend function.

The electricity prices used to develop the annualized fuel costs, in the default mode, are region- and end-use-specific prices developed as averages of time-of-day rates weighted by expected time-of-use patterns. The incorporation of prices relevant to a particular end-use service allows for consideration of varying price and rate structures in the electric power markets, although the regional specification of the EMM and CDM require careful aggregation and weighting to represent the complexity of regulatory and business models in today's markets. Average annual prices by census division are used to develop the annualized fuel costs for the other major fuels.

In the case of lighting technologies, the yearly fuel cost component includes an adjustment to take lighting output quality into account. The *TechCRI* factor uses the lighting color rendering index (CRI) that characterizes the relative light quality based on the spectrum of natural light output by the particular technology. The adjustment reduces the *effective efficiency* of low-CRI lighting technologies, rendering them less attractive relative to higher CRI options.

The actual calculation of the annualized cost for comparison of candidate technologies is performed using Equation B-64. For decisions regarding space heating and cooling equipment, the calculation includes a shell efficiency load factor, incorporating the effects that building shell improvements have on annual fuel costs for heating and cooling. The shell efficiency factors, illustrated in Equations B-61 and B-62, use the same load factors calculated in the Service Demand Submodule. The effective hurdle (implicit discount) rate used in Equation B-64 is given by Equation B-63 and is discussed in the section on risk-adjusted time preferences.

The cost relevant to consumers and the menu of technologies vary by consumer and choice. Therefore, a distribution of technologies, rather than a single technology, is chosen when the decisions of various consumers are consolidated. A distribution is more representative of consumer response than assuming that all consumers choose the same technology. In the CDM, technology choice decisions are made through nine combinations of commercial consumer behavior rules and decision types. These combinations are presented in Table 9 and are described in greater detail below.

Table 9. Array of technology choices and consumer behaviors

	Decision type		
Behavior rule	**New**	**Replacement**	**Retrofit**
Least-cost	New equipment, least-cost rule	Replacement equipment, least-cost rule	Retrofit decision, least-cost rule
Same-fuel	New equipment, same-fuel rule	Replacement equipment, same-fuel rule	Retrofit decision, same-fuel rule
Same-technology	New equipment, same-technology rule	Replacement equipment, same-technology rule	Retrofit decision, same-technology rule

Behavior rules

The NEMS CDM simulates a range of economic factors influencing consumer purchase decisions by assuming that consumers use one of three behavior rules in their technology choice decisions:

- Least-cost rule—Purchase the equipment with the smallest annualized cost without regard to currently installed technologies or fuels used
- Same-fuel rule—Purchase equipment that uses the same fuel as existing or retiring equipment, but within that constraint still minimizes costs
- Same-technology rule—Purchase (or keep) the same class of technology as the existing or retiring equipment, but choose the model within that technology class that minimizes the annualized costs

The same basic decision logic applies to all of these rules, but the behavior rule determines the set of technologies from which the selection is made. A consumer following the least-cost behavior rule chooses from all available technologies and all available fuels. A consumer following the same-fuel behavior rule chooses from a more restrictive array of technologies. A consumer following the same-technology behavior rule would select from one class of technologies, choosing among all available models of equipment in that class.

As discussed above, the CDM segments consumers into three behavior rule categories. Ideally, survey data would indicate what proportion of the commercial sector follows each rule. The Technology Choice Submodule currently incorporates proportions by building type and decision type based on an analysis of data from multiple rounds of the CBECS. Data regarding the ownership and occupants of commercial buildings form the basis of proportions of the market that act according to each behavior rule for each decision type. Special considerations and interactions between the behavior rules and decision types are described in the section on decision types. We combine the CBECS data with other data characterizing consumer behavior obtained from published literature to develop the behavior rule proportions incorporated in the module.[22] Changing these proportions affects final consumption estimates.

22 Further discussion regarding the behavior rule assumptions and specific references for the published literature on consumer behavior is provided in the Appendix E discussion on data quality for user-defined parameters.

The supporting data from CBECS, including building stock ownership patterns, are presented in Table 10. The following categories are provided:

- Total Floorspace of All Buildings
- Total Floorspace of All Non-Government-Owned Buildings
- Owner Occupied
- Non-Owner Occupied

Specific ownership categories developed from this data include the following:

- Non-Government, Non-Owner Occupied, which is the difference between Total Non-Government-Owned and Non-Government Owner Occupied
- Government-Owned, which is the difference between Total Floorspace and Non-Government-Owned buildings

This disaggregation, combined with analysis of consumer behavior literature, results in the behavior rule proportions. The methodology to develop these proportions is described below. The three issues that are examined to determine which behavior rule applies are construction, ownership, and occupancy. Appendix A provides additional documentation and sources for the information in Table 10 and this discussion.

The behavior rule that applies when constructing new buildings is sensitive to the party that is financing the construction. The behavior in selecting equipment in new construction is assumed to differ between those projects that are self-built and those that are built by speculative developers. For each building type, which is the modeled representation of all projects for each region and use, a proportion is assumed to be self-built and developer-built.

The ownership and occupancy of buildings provides some insight into the proportions for the replacement and retrofit decision types. In a replacement decision case, it is assumed that government and owner-occupied buildings will replace most equipment with either the same technology or a technology that uses the same fuel. Owner-occupied floorspace is likely to have similar proportions between same-technology and same-fuel rules. Renter-occupied floorspace is most likely to replace the existing technology with the same technology.

Table 10. Base-year floorspace ownership and occupancy (2018)

Building type	Total floorspace	Government owned		Non-government owned		Owner occupied		Non-owner occupied		Self-built	Speculative developer
	(MM ft^2)	(MM ft^2)	Percent	(MM ft^2)	Percent	(MM ft^2)	Percent	(MM ft^2)	Percent	Percent	Percent
Assembly	12,578	2,679	21.30%	9,899	78.70%	11,419	90.78%	1,159	9.22%	87.00%	13.00%
Education	13,638	10,621	77.88%	3,016	22.12%	12,558	92.09%	1,079	7.91%	96.00%	4.00%
Food sales	1,005	0	0.00%	1,005	100.00%	707	70.36%	298	29.64%	34.00%	66.00%
Food service	1,385	287	20.73%	1,098	79.27%	920	66.43%	465	33.57%	52.00%	48.00%
Health care	2,293	347	15.12%	1,946	84.88%	2,113	92.13%	180	7.87%	76.00%	24.00%
Lodging	6,856	415	6.05%	6,441	93.95%	4,828	70.41%	2,028	29.59%	29.00%	71.00%
Mercantile/ service	10,595	2,222	20.97%	8,373	79.03%	6,026	56.88%	4,568	43.12%	34.00%	66.00%
Large office	7,744	1,252	16.17%	6,492	83.83%	4,663	60.21%	3,081	39.79%	42.00%	58.00%
Small office	17,110	1,145	6.69%	15,965	93.31%	8,907	52.05%	8,204	47.95%	27.00%	73.00%
Warehouse	17,717	619	3.49%	17,097	96.51%	9,450	53.34%	8,267	46.66%	30.00%	70.00%
Other	5,606	2,032	36.24%	3,575	63.76%	4,329	77.22%	1,277	22.78%	61.00%	39.00%
Total	96,527	21,619	22.40%	74,908	77.60%	65,919	68.29%	30,608	31.71%	44.00%	56.00%

The general description of the technology choice procedure described above does not mean that all consumers simply minimize the costs that can be measured. A range of economic and other factors influence technology choices. For example, a hospital adding a new wing has an economic incentive to use the same fuel as in the existing building. There are also economic costs associated with gathering information for purchase decisions and with managerial attention. Decision procedures for specific agents often include noneconomic factors such as business model, organizational culture, and local or site-specific factors. The representation of consumer behavior in the CDM allows econometric analysis to inform the flexible but necessarily simplified optimization framework, thus incorporating observed historical behavior stemming from the full range of factors.

Decision types and their relationship to behavior rules

The CDM's behavior rules that determine how consumers select technologies are intended to represent agents acting in a range of situations. The reasons for purchasing equipment in such differing situations are referred to as decision types and are described below. Commercial sector consumers have three equipment purchase decision types:

- New—Choose equipment for new buildings
- Replacement—Choose replacement equipment for retiring equipment in existing buildings
- Retrofit—Choose retrofit equipment to replace equipment that continues to function in existing buildings or leave existing equipment in place

The Service Demand Submodule computes the total amount of service demand falling into each of the three decision-type categories given above. The Technology Choice Submodule must next determine the mix of equipment and corresponding fuel shares represented in the replacement and retrofit decision types. This determination is accomplished by Equations B-54 through B-58 in Appendix B.

For new buildings, consumers using the least-cost behavior rule choose from among all current technologies and all fuels. Identification of the least-cost equipment from the perspective of each consumer time preference segment is made in two stages. Identification of the least-cost fuel is made in stage 1 using Equation B-67 with the unadjusted distribution of hurdle rates as indicated in Equation B-63. Stage 2 of the least-cost behavior decision evaluates Equation B-68 from among technologies that use the same fuel as chosen in stage 1 and includes effective hurdle rates that adjust with increasing real energy costs as discussed in the section on risk-adjusted time preferences. Consumers using the same-fuel behavior rule choose from among current technologies that use the same fuel as surviving buildings (buildings that do not retire). Identification of the least-cost equipment for each fuel from the perspective of each consumer risk-adjusted time preference segment is made using Equation B-69. Proportions of consumers in this category who choose each fuel are assumed to equal the overall fuel shares that prevailed in existing buildings during the previous year, which is reflected in the individual terms of Equation B-73. Similarly, the identification of least-cost models for each technology for the consumers following the same-technology rule is illustrated by Equation B-70. As with the same-fuel rule, the proportions of consumers within this segment that stick with each particular technology class is assumed to equal the overall market share distribution of those technologies within existing buildings during the previous year, as reflected in the individual terms of Equation B-75.

For equipment replacement decisions, consumers using the least-cost behavior rule choose from among all current technologies in two stages, as described for new buildings and illustrated by Equations B-67 and B-68. Consumers using the same-fuel behavior rule choose from among current technologies that use the same fuel as was used by the retiring equipment. The proportions of consumers within the same-fuel rule attempting to preserve the use of each fuel are equal to the fuel shares represented in aggregate by the equipment in need of replacement, as reflected in the individual terms of Equation B-74. Consumers using the same-technology behavior rule choose the least costly vintage of the same technology as the technology in need of replacement. As with the same-fuel rule, the proportions of consumers within the same-technology category attempting to retain equipment within each technology class are equal to the market shares of retiring equipment classes within the aggregate service demand in need of replacement, as reflected in the individual terms of the right side of Equation B-76.

For the retrofit decision, which involves the choice between retaining equipment that continues to function and replacing it with new equipment to reduce costs, the costs of purchasing new equipment as described above must be compared against the cost of retaining existing equipment. To make this comparison, the existing equipment capital costs are considered sunk costs, meaning that these costs are set to zero. If retrofit equipment is purchased, the decision maker must pay the capital and installation costs of both the existing equipment and the retrofit equipment. If existing equipment is retained, the decision maker continues to pay just the capital and installation costs of the existing equipment. Therefore, the capital and installation costs of existing equipment are netted out because they are irrelevant to the retrofit decision (this analysis assumes zero salvage value for existing equipment). The cost calculation is similar to that illustrated by Equation 6 above, except without the purchase and installation component. However, the cost of removing and disposing of existing equipment must be considered. This cost is expressed in the CDM technology characterization database as a specified fraction of the original purchase and installation cost, and it is annualized over the equipment lifetime. The resulting calculation of the annualized cost of retaining the existing equipment is given by Equation B-79. As in the calculation of the annualized cost of new equipment, the annualized cost of retaining existing space heating or cooling equipment includes fuel costs, which depend on shell efficiency factors illustrated in Equations B-61 and B-62, and the effective hurdle rate given in Equation B-63**.**

For the equipment retrofit decision, consumers using the least-cost behavior rule choose from among all current technologies in two stages as described for new buildings, comparing the cost of each as expressed by Equations B-64 and B-65 against the cost of retaining the existing equipment as expressed by Equation B-79, and choosing the least-cost result, as illustrated by Equations B-81 and B-80. Consumers using the same-fuel behavior rule choose from among current technologies, which use the same fuel as is currently used by the existing equipment, again comparing the cost of each against the cost of retaining the existing equipment, and choosing the least costly alternative, as indicated by Equation B-82. Two options are available in the CDM to represent the choice behavior of consumers using the same-technology behavior rule for the equipment retrofit decision. One option, used in the AEO Reference case, is to allow selection from among available models in the same technology class, comparing the cost of each against the cost of retaining the existing equipment, and choosing the least costly alternative, as illustrated by Equation B-87. Alternatively, all consumers using the same-technology behavior rule may be assumed to retain their existing equipment, as indicated by Equation B-86. The choice of methods is specified through the CDM user parameter named STRetBehav.

The equipment selections made for each of the decision types and behavior rules described above will vary according to the risk-adjusted time preference held by the consumer. These risk-adjusted time preferences are discussed below in preparation for the description of the consolidation of equipment choices to obtain the final equipment market shares.

Risk-adjusted time preferences

This distribution is a function of factors aside from the market interest rate that render current dollars preferable to future dollars. The CDM is designed to accept a distribution of risk-adjusted time preferences as input. This distribution is discrete; it takes the form of a list of real risk-adjusted time preferences and a proportion of commercial consumers corresponding to each risk-adjusted time preference.[23] The risk-adjusted time preference distribution is modeled independently of the behavior rules. The risk-adjusted time preference, which appears as an interest rate premium, is intended to

[23] A substantial amount of literature attempts to explain why consumers (in the general sense of the word, including businesses) choose not to invest in energy-efficient equipment that seems to make economic sense at prevailing market interest rates. Conceptual explanations have included uncertainty about future energy prices, lack of information regarding the performance and cost of particular types of energy-efficient equipment, disruption costs for businesses, energy costs' typically small share of commercial business expenses, competing investments considered more important than efficiency, and uncertainty about future technologies (buying too soon may lock in to a less-efficient technology). For a review of these issues, see Chapter 4 of Gillingham K., R. Newell and K. Palmer (2009). "Energy Efficiency Economics and Policy" Annual Review of Resource Economics 2009.1: 597−619. Some further considerations and specific implications for NEMS are discussed in the 2013 EIA Technical Workshop on Behavior Economics, op cit.

reflect differences in consumer preferences between capital costs (paid initially) and fuel and O&M costs (incurred over the lifetime of the equipment). The value of this interest rate premium influences the annualized installed capital cost through an annuity payment financial factor based on the 10-year Treasury note rate, the risk-adjusted time preference premium, and expected physical equipment lifetime. The sum of the 10-year Treasury note rate and the consumer risk-adjusted time preference premium is referred to as the implicit discount rate, in other words, the interest rate required to reflect actual purchases. The implicit discount rate is also known as a hurdle rate to emphasize consideration of all factors, both financial and nonfinancial, that affect an equipment purchase decision. The combination of these factors results in the height of the *hurdle* for the purchase decision. A 3% discount rate floor is set per Federal Energy Management Program (FEMP) Title 10 code of federal regulations (CFR) § 436.14.

The model results are sensitive to the distribution of the risk-adjusted time preference premiums. If the distribution is denser at the high premiums, the annualized cost of capital for all new equipment will rise. Higher annualized capital cost implies that fewer buildings will be retrofitted and that equipment that has a higher installed capital cost is less likely to be chosen over a technology with a lower initial cost and higher operating and fuel costs. Typically, those technology and vintage combinations with high installed capital costs are high-efficiency pieces of equipment so that the indirect effect of this scenario is that fuel consumption is likely to be higher. We developed the values currently used in the CDM by using case studies on the payback period or risk-adjusted time preferences regarding the adoption of a specific technology and recent surveys that examine perceptions of energy efficiency and green building practices.[24] The model allows variation in the distribution on an annual basis to accommodate simulation of policy scenarios targeting consumers' hurdle (or implicit discount) rates. The distribution of consumer risk-adjusted time preference premiums includes adjustments to reflect legislation affecting federal purchasing requirements, to account for funding provided in ARRA09 and to incorporate survey findings. The distribution is assumed constant over the projection period after 2018.[25] The module currently uses expected physical equipment lifetime as the discount horizon. Appendix A provides additional documentation and sources for the distribution of risk-adjusted time preference premiums.

The distribution of hurdle rates used in the CDM is affected by changes in fuel prices in addition to any annual changes input by the model user. If a fuel price rises relative to its price in the base year, the nonfinancial portion of each hurdle rate in the distribution decreases to reflect an increase in the relative importance of fuel costs expected in an environment of rising fuel prices. The function representing the fuel price effects on hurdle rates is given by Equation B-63. Parameter assumptions result in a 30% reduction in the nonfinancial portion of a hurdle rate with a doubling of fuel prices, down

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[24] Results of surveys conducted by Johnson Controls and Building Design+Construction were considered. See Appendix A for reference information and Appendix E for a more detailed discussion of hurdle rate development.

[25] EPACT05 and EISA07 update energy intensity reduction goals and performance standards for federal buildings. EISA07 also mandates use of energy-efficient lighting fixtures and bulbs in federal buildings to the maximum extent feasible. ARRA09 stimulus funding is assumed to affect purchasing decisions for state and local governments and for federal agencies. The discussion of the distribution of risk-adjusted time preference premiums in Appendix A addresses the adjustment to the assumed proportion of consumers using specific time preferences to capture the federal purchasing requirements and effects of stimulus funding as a result of these provisions.

to a total hurdle rate of 15%, the assumed financial discount rate. If the risk-adjusted time preference premium input by the model user results in a hurdle rate of less than 15% with base-year fuel prices, no change in hurdle rate in response to increasing fuel prices is assumed.

Consolidate choices from segments

Once the technology choices have been made for each segment, these choices must be consolidated to obtain equipment market shares by building type, census division, and decision type for that end use. From these market shares, average efficiencies of the equipment mix and fuel shares may be obtained, which form the basis of the Consumption Submodule calculated fuel consumption.

The first step in consolidation involves combining the results obtained from the perspective of each consumer risk-adjusted time preference segment to calculate market shares of equipment within each behavior rule segment of each decision type. Because each risk-adjusted time preference segment makes only one equipment selection within each decision type and behavior rule, we compute the market share of that equipment type for that decision type and behavior rule segment by simply adding up the proportions of consumers contained in each risk-adjusted time preference segment that selected the equipment. This calculation is performed by Equations B-71 through B-76 and B-84 through B-86, using the factors associated with same-fuel and same-technology proportions described previously.

The next step in the consolidation process is to calculate the market shares of equipment within each decision type, consolidated across the behavior rule segments. This step uses Equations B-77, B-78, and B-87 to obtain equipment market shares for the new, replacement, and retrofit decisions, respectively. These shares and the previously described consolidation may be viewed as weighted sums, using as weights the quantities described in Table 11.

Table 11. Consolidating service demand segments

Segmenting variable	Weighting variable for consolidating segments
Behavior rule	Behavior rule service demand proportions
Consumer’s time value of money preference	Consumer risk-adjusted time preference proportions

After this point, all equipment used to provide the major services receives identical treatment, but the calculation of equipment market shares described above differs for the case of heat pumps. The purchase decision for heat pumps integrates decisions for providing both space heating and space cooling because selecting the same heat pump for two services is not realistically accomplished using two independent decisions. Furthermore, if the utility of the heat pump for providing additional services is not considered during the purchase decision, then the total heat pump cost may appear unreasonably high in comparison with other equipment providing the service under consideration. Both of these considerations have been resolved in the current version of the CDM using the following approach.

First, we assume heat pumps provide both space heating and cooling when purchased, but they are considered for purchase during the course of satisfying demands for space heating. Heat pumps compete with other available space heating equipment in the normal fashion during the technology choice process with one notable exception: the installed capital cost of the heat pump for heating is not the total cost of purchasing and installing the heat pump, but rather it is the incremental cost of doing so over and above the cost of purchasing and installing a standard cooling equipment selection specified by the user. This understanding captures the fact that the heat pump provides both space heating and space cooling and yet has only one purchase and installation cost. This adjustment to the installed capital cost retrieved from the technology characterization database is performed using Equation B-59.

During the technology choice process for satisfying space cooling service demands, heat pumps are excluded from selection as a result of the assumption that heat pumps will provide both space heating and cooling. Instead, market shares of cooling service demand satisfied by heat pumps are derived from the heat pumps selected to provide space heating by assuming that the ratio of cooling to heating delivered by a heat pump over the course of the year is equal to the ratio of cooling degree days to heating degree days for the census division under consideration. From this assumption, the amount of cooling service demand satisfied by heat pumps is calculated as well as their market shares of cooling service demand. This calculation is performed by Equation B-88. To account for the fact that equipment shares of cooling equipment other than heat pumps apply only to that portion of cooling service demand not satisfied by heat pumps, a final correction of the non-heat pump market shares is then performed by Equations B-91 and B-92.

Fuel shares of service demand for the major services and fuels are calculated by summing the equipment market shares of service demand of equipment using each fuel. This calculation is performed by Equation B-92 within the decision type segments by end use, fuel type, building type, and census division, and by Equation B-94 consolidated across decision types. Equations B-100 through B-102 calculate the fuel shares by decision type, end use, fuel type, and census division consolidated across building type.

Average efficiencies of the equipment mixes within various segments are calculated using the inverse weighted efficiency approach exhibited by Equations B-93, B-96 through B-99, and nationally by end use and fuel using Equation B-103. The particular form of the averaging is necessary because efficiencies possess units of delivered to consumed energy, whereas the equipment market shares used as weights are proportions of delivered energy. Only if the equipment market shares were expressed as proportions of consumed energy would the average efficiency of the equipment mix be obtained using a simple weighted sum of market shares and corresponding efficiencies.

Finally, fuel shares and average efficiencies are determined for the minor services, without considering individual equipment choices given to the major services. As described previously, the base-year average efficiencies for the minor services are indexed to unity. The user may provide an exogenous projection of minor service efficiency improvement for any of the minor services via the EffGrowthRate parameter described in Appendix A. With this option, minor service average efficiency for the current year is calculated from the value for the previous year. The exogenously specified efficiency growth rate is shown in Equation B-104. Projected changes in computing and office equipment energy consumption are explicitly included in the computing and office equipment projections described in Appendix A under Market Penetration, so the EffGrowthRate is set to zero for the computing and office equipment end-use services. Expected efficiency improvements are also explicitly included in the trend projections for specific categories within miscellaneous electric loads (MELs). Efficiency improvement for the non-specific portions of MELs is set to zero as a result of a lack of information. However, the option remains available to facilitate analysis of programs aimed at improving efficiency in this area. Minor services are further assumed to possess identical average efficiencies for all decision types and buildings within a certain census division and year, as illustrated by Equation B-105. Office equipment services are assumed to use only electricity.

Technology menu

The technology cost and performance assumptions used in the calculations of consumer choice are organized into a *technology menu*. Many relevant characteristics are used in the CDM, many of which are specified exogenously or by the user. The following set of parameters is specified exogenously:

- Equipment availability
- Installed capital costs
- Removal and disposal cost proportions of installed capital costs
- Operating and maintenance costs
- Building restrictions
- Energy efficiencies
- Lifetimes
- Lighting quality factors
- Technology cost trends

The technology menu also incorporates rebates for appliances that achieve ENERGY STAR or greater energy efficiency levels, which are subtracted from installed capital cost when determining technology choice.

Equipment availability pertains to the set of technologies currently in the marketplace during a particular projection year; not all available technologies are economically feasible, and non-economical technologies will not be selected. The menu of potential technologies includes technologies that are currently under development to be introduced over the projection period. Equipment supply is assumed to be unlimited for commercially available technologies, and unit costs either are fixed or decline according to the appropriate cost trend function. The other equipment characteristics are assumed fixed for each technology and vintage once it is commercially available.

For the case of certain prototypical or *design-stage* technologies currently not available in the marketplace (or currently not in production), engineering specifications form the basis of the technology characterization. These costs may differ markedly from the actual technology costs when the equipment is introduced to the real-world marketplace.

The base-year initial historical market shares are based on an analysis of CBECS data. The years of equipment availability are based on current market conditions and research as well as mandated federal efficiency standards. This window in which each technology vintage is available constrains the technology choice menu for all decision types. For example, a commercial refrigerated vending machine available in 2015 may no longer be available in 2019 as a result of federally mandated minimum equipment efficiency standards.

An option to allow endogenous price-induced technology changes has been included in the determination of equipment costs and availability for the menu of equipment. This concept allows future technology improvements faster diffusion into the marketplace if fuel prices increase markedly for a sustained period of time. The option is activated through the setting of a CDM user parameter named IFMAX, which governs the maximum number of years the availability of a technology vintage can potentially be shifted forward. The formulation only works in one direction; that is, equipment can only be shifted toward earlier availability, and once shifted, a vintage will not be shifted back to its original availability date. In addition, shifts are limited to a lesser number of years for nearer-term technology vintages to ensure that future improvements cannot become available before the persistent price change is projected to occur. Equations B-106 and B-107 illustrate the calculations needed to move an availability date forward through price-induced technology change. The parameter is currently set to 0 years for reference and core side-case model runs, effectively assuming that there is no endogenous change.

End-Use Consumption Submodule

The End-Use Consumption Submodule models the consumption of fuels to satisfy the demands for end-use services computed in the Service Demand Submodule. In addition, the End-Use Consumption Submodule projects the consumption of fuels to provide district energy services in the commercial sector, accounts for the net effects of distributed generation and CHP on fuel consumption, and accounts for the use of solar thermal energy to provide space heating and water heating.

The primary inputs to the End-Use Consumption Module are the service demands calculated by the Service Demand Submodule and the fuel shares and average efficiencies projected by the Technology Choice Submodule. Together, these quantities allow a basic calculation to be made for consumption of the major fuels that has the same form for both the major and minor services. This calculation, given by Equation B-108, uses the definition of average efficiency to obtain the projected consumption by fuel, end use, building type, census division, and year by dividing that portion of the end-use service satisfied by each fuel by the average efficiency of equipment using that fuel. A value of zero for the average efficiency indicates that no equipment consuming the fuel is used to satisfy the service, and in this case, the corresponding consumption projection is explicitly set to zero. Because the units carried for lighting service demand and efficacy differ from those of the other services, a special conversion factor must be applied to the lighting result, as shown by Equation B-109.

The basic estimate of fuel consumption described above is the projected estimate expected to occur if all conditions other than the amount of floorspace, the building shell efficiency, and the equipment mix were identical to those found in the base year, and if consumers were only concerned with fuel prices insofar as they impacted equipment purchase decisions. Because conditions other than those mentioned above vary with time, and because consumers are also concerned with fuel prices when using the equipment they have purchased, the basic estimate is subject to modification by several considerations.

First, a price elasticity of service demand may alter the consumer's demand for a service as a result of a change in the fuel price. As an example, an increase in the price of distillate fuel oil may cause the consumer to maintain the floorspace at a somewhat cooler temperature in the winter than would have been the case without a price increase. Although this consideration should logically be made where service demands are calculated in the Service Demand Submodule, it is not possible at that point because the mix of equipment using each fuel is not calculated until the Technology Choice Submodule has completed its projection. However, the calculation is easily made by the End-Use Consumption Submodule because of the direct proportionality between service demand and fuel consumption, as can be seen in Equation B-108; that is, a percentage change in service demand corresponds to the same percentage change in fuel consumption. The highly aggregated nature of the service demand as modeled at the regional geographic scale further enables this approach. The actual units of demand are not subject to the strong economies of scale, which can induce threshold effects in sectors, such as electric power supply, in which *lumpy capital* can produce a suboptimal investment path when demand changes by a small amount after technology is chosen. The calculation of the short-run price elasticity of demand incorporates a graduated or *lagged* adjustment that allows the degree of consumer response to vary with significant changes in fuel prices. Equation B-110 illustrates the function used to calculate the short-run elasticity adjustment. The first term in Equation B-111 shows the application of the short-run price elasticity of demand to modify the basic consumption estimate obtained by Equation B-108.

Another consideration that affects the consumer's demand for services is known as the *take-back* or *rebound* effect. Although fuel price increases can be expected to reduce demand for services, this trend can be partially offset by other factors that cause a decrease in the marginal cost of providing the service. Two such factors modeled by the End-Use Consumption Submodule are the responses to increased average equipment efficiency and improved building shell efficiency. The proportional change in the marginal cost of service provision as a result of movement in each of the aforementioned factors relative to their base-year values is calculated and combined with a modified price elasticity of service demand parameter to yield the computed effect on fuel consumption, as shown by the second and third terms of Equation B-111. Because these modifications to the basic consumption estimate are each multiplicative, Equation B-111 is capable of accommodating independent changes in each of the underlying driver variables (fuel price, average equipment efficiency, and building shell efficiency) regardless of the directions of movement. Although the rebound effect as a result of equipment efficiency improvement is considered for the end-use services of space heating, space cooling, water heating, ventilation, cooking, and lighting, the rebound effect as a result of building shell improvement is considered only for space heating and space cooling. The equipment and building shell efficiency rebound elasticity parameters currently included in the CDM are set to -0.15 for these services.[26]

A final modification to the basic estimate of fuel consumption is made in the form of a weather correction, which accounts for known weather abnormalities during historical years of the projection period and differences between the base-year weather and weather trends anticipated in future years. The basis for the weather correction is the number of population-weighted heating and cooling degree days by census division based on thirty years of historical heating and cooling degree days for each state. This 30-year trend informs the projection of state-level degree days, which are exogenously

[26] The current parameter values for the rebound effect are within the range of short-run empirical responses found for firms as presented in the literature review by Greening, Greene, and Difiglio in a special issue of the journal Energy Policy. See Greening, L.A., D.L. Greene, and C. Difiglio, Energy efficiency and consumption - the rebound effect - a survey, Energy Policy, Vol. 28, Nos. 6-7 (June 2000), pp. 389-401.

aggregated to the census division level using state-level populations. The 30-year linear trend is adjusted over the projection period to account for state population shifts. Space heating and cooling consumption in projection years is modified by considering the heating and cooling requirements in each year relative to those prevailing in the base year. This modification is accomplished for heating consumption using a multiplicative factor equal to the ratio of the appropriate degree days, as shown by Equation B-112. Equation B-113 illustrates the weather correction for space cooling requirements, including an exponential term to reflect the nonlinear relationship between weather and cooling requirements.

Applying the price elasticity and rebound effect considerations, together with the weather correction, to the basic estimate of fuel consumption by end use provides an enhanced projection of demand for the major fuels of electricity, natural gas, and distillate fuel oil by equipment directly satisfying the 10 basic end-use services. Consumption of the minor fuels of residual fuel oil, propane, steam coal, motor gasoline, and kerosene is calculated using a different approach, as is consumption for purposes not yet explicitly modeled, including consumption to provide district energy services and *non-building* consumption (consumption in the commercial sector not attributable to end uses within buildings, such as street lighting and municipal water services).

Consumption of minor fuels is projected from the first trend year to 2022 using log-log regression equations on historical census division-level consumption, floorspace, and pricing data. The regression parameters are obtained from the correlation of minor fuel consumption per square foot of commercial floorspace with respect to the corresponding fuel price in constant dollars, restricting to the most recent years which share the same linear trend (Equation B-127). The minor fuel regression parameters were developed using historical census division-level minor fuel consumption and pricing data from the State Energy Data System (SEDS, 1960-2022) and the Dodge Data & Analytics (DDA) estimated floorspace database (1970 to 2022).[27] Finally, the estimated parameters are applied to project minor fuel energy use intensity (EUI). This EUI is multiplied by projected commercial floorspace to produce projected minor fuel consumption.

The End-Use Consumption Submodule also accounts for nonutility generation of electricity by the commercial sector using distributed generation and CHP technologies, together with the quantities of fuels consumed to accomplish electricity generation and CHP as described in the Distributed Generation and CHP section. End-use consumption of purchased electricity is reduced as given by Equations B-114 through B-116 to reflect the use of self-generated electricity. Equation B-117 calculates reduction in space and water heating consumption through use of heat generated by CHP technologies. Equation B-118 accounts for fuel consumption by distributed generation and CHP technologies.

The final component of the End-Use Consumption Submodule is an estimation of the quantities of fuel consumed to provide the district energy services of space heating, space cooling, and water heating. District energy services involve the localized production of steam energy that is used to provide

[27] The Dodge Data & Analytics historical floorspace data from 1970 to 2022 was used to estimate minor fuel parameters, supplementingCBECS data to estimate the model. CBECS surveys were conducted triennially between 1979 and 1995 and quadrennially between 1995 and 2007. The most recent CBECS data is from 2012 and 2018. The Dodge Data & Analytics database is proprietary.

distributed end-use services over a wide area, such as a campus environment or urban center. Estimates of the steam EUI by census division, building type, and end-use service for district energy services were prepared separately from those estimates previously described for the standard end-use services. These estimates of the steam EUI are used in conjunction with typical efficiencies and census division-level fuel shares for the systems providing district energy services, together with the floorspace projection, to produce the projection of fuel consumption for district energy services, as shown by Equation B-119. Price elasticity considerations and the weather correction are applied to district energy services fuel consumption in the same manner as they are applied to direct fuel use for end-use services as shown by Equation B-120.

The consumption projection by census division, fuel, end-use service, and building type is incremented by the district energy service consumption estimate just described, as shown by Equation B-122. Aggregation of this result across end-use services and building types yields the projection of fuel consumption by fuel and year at the census-division level required by the other NEMS modules, as shown by Equation B-129. Another aggregation across fuels and census divisions is performed to obtain the national-level projection of total energy consumption by building type, to which is added the use of solar thermal energy for space heating and water heating, as shown by Equation B-130. Additional results are also aggregated in various ways to satisfy reporting requirements, as illustrated by the End-Use Consumption equations not discussed. One final consumption component, representing non-building consumption, is calculated in the Benchmarking Submodule, described in the next section.

Benchmarking Submodule

The Benchmarking Submodule reconciles the fuel consumption projection produced by the End-Use Consumption Submodule with data from the State Energy Data System (SEDS). SEDS contains historical fuel consumption data chosen to serve as a standard for the NEMSNEMS over the historical period of the projection. In addition, the Benchmarking Submodule provides an option for considering results from EIA's *Monthly Energy Review* (MER) and *Short-Term Energy Outlook* (STEO) for the near term immediately beyond the last year of SEDS data availability. Definitional differences between SEDS and CBECS, on which the Commercial Sector Module is based, are used to construct a projection of commercial sector fuel consumption not attributable to end uses within buildings.

Equation B-131 illustrates the calculation of the *SEDS mistie*, or discrepancy between the End-Use Consumption Submodule results and SEDS data, during years for which SEDS data exist. Because SEDS data are estimates of all consumption by the commercial sector, whereas CBECS applies only to consumption within commercial buildings, the difference between the End-Use Consumption Submodule's CBECS-based fuel consumption projection and the SEDS data is attributed to fuel consumption for non-building uses, as shown by Equation B-133. This assignment is performed for each year of the projection period for which SEDS data are available. The use of the SEDS data through the year indexed as MSEDYR+1 in these calculations reflects the fact that the MER provides reliable estimates of consumption data for an additional year beyond the latest published SEDS results, and these estimates are used in the same manner as published SEDS data.

After the final year of SEDS data availability, electricity consumption for non-building uses is projected to grow at the same rate as commercial floorspace. This expectation follows from the observation that, while not representing fuel consumption within buildings, the non-building uses are generally associated with commercial buildings or activities, as in the case of water or telecom utilities. The projection of SEDS-based consumption of electricity for non-building uses beyond the last year of SEDS data availability is shown by Equation B-135. The projection of electricity use for municipal water services and telecom services as a component of non-building uses is illustrated in Equations B-136 through B-140. Non-building use of natural gas, distillate fuel oil, and minor fuels is not expected to grow at the same rate as commercial floorspace, but instead it is expected to remain at a relatively constant level, as illustrated by Equation B-142,

The CDM includes an option to activate benchmarking to that portion of the STEO projection immediately following the last year of historical data. This option is accomplished through the setting of a NEMSNEMS-wide parameter named STEOBM and a CDM user parameter named ComSTEOBM. Both parameters must be set to activate benchmarking to the STEO projection. If selected, the benchmarking is incremental; that is, it is calculated based on the projection produced after benchmarking to SEDS. For years covered by the short-term STEO projection, the calculation of the discrepancy between the SEDS-benchmarked projection and STEO is given by Equation B-134 for electricity. Equation B-141 gives the corresponding calculation for natural gas, distillate fuel oil, and minor fuels. An additional option allows STEO benchmarking adjustments to result in fuel use projections that are within 2% of the STEO projections, as illustrated in Equation B-143. Equation B-144 shows the addition of the STEO-based incremental component of non-building consumption to the component based on SEDS.

If the STEO benchmarking option is chosen, one of two options for avoiding a discontinuity in the benchmarked projection beyond the last year of STEO data must also be selected. The simplest option is to retain the STEO component of non-building use calculated for the last year of STEO data availability and apply it to the projections for all future years. Alternatively, the STEO component of non-building use can be ramped down to zero over a specified time period following the last year of STEO data. This method is currently used, and ramp-down years are set in the KPARM.TXT input file. The choice of methods is specified through the CDM user parameter named DecayBM. Calculation of a time-dependent decay factor based on the selection of the various options is illustrated by Equation B-145. Equation B-146 illustrates the optional addition of a STEO-based component of non-building consumption to that based on SEDS for projection years after the final year of STEO data availability.

The addition of the projection of fuel consumption for non-building uses to that produced by the End-Use Consumption Submodule for end uses within buildings completes the projection of commercial sector fuel consumption, as shown by Equation B-147.

Appendix A. Input Data and Variable Descriptions

Introduction

This appendix describes the input data, parameter estimates, variables, and data calibrations that currently reside on EIA's computing platform for the execution of the NEMS Commercial Demand Module (CDM). These data provide a detailed representation of commercial sector energy consumption and technology descriptions that support the module. Appendix A also discusses the primary module outputs.

Table A-1 references the input data, parameter estimates, variables, and module outputs documented in this report. For each item, Table A-1 lists an equation reference to Appendix B of this report, a subroutine reference, the item definition and dimensions, the item classification, and units. Note that all variables classified as *Calculated Variable* can also be considered to fall into the *Output* classification because they are located in common blocks accessible to other NEMS modules and external programs. The references for items pertaining to the Distributed Generation and Combined Heat and Power (CHP) Submodule are found at the end of Table A-1.

Following Table A-1 are profiles of the model inputs. Each profile describes the data sources, analytical methodologies, parameter estimates, NEMS input file, and source references.

The remainder of Appendix A contains supporting discussion, including data selection and calibration procedures, required transformations, levels of disaggregation, and model input files.

NEMS Commercial Demand Module inputs and outputs

This section organizes model inputs and outputs alphabetically and provides links to their appearance in the numbered equations of Appendix B. The Fortran subroutine in which the equation is implemented is also listed. Definitions are provided as well as classifications (inputs, parameters, or calculated variables) and units of measurement.

Table A-1. NEMS CDM inputs and outputs

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
ACE	B-79	Technology Choice	Annualized life-cycle cost of retaining existing equipment relative to retrofitting, per unit of delivered service, by technology class, technology vintage, and consumer risk-adjusted time preference premium. Calculated for each census division and building type during each iteration of each projection year. Incorporates building capacity utilization factor, yearly operating and maintenance cost, annualized fuel costs,	Calculated variable	Non-lighting, non-ventilation: Constant dollars/(thousand British thermal units [Btu] out per hour)/year Lighting: Constant dollars/thousand lumens/year Ventilation: Constant dollars/thousand cubic feet per minute (CFM)

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			projected interest rates, and consumer risk-adjusted time preference premiums. Treats unit installed capital cost of existing equipment as sunk cost, but considers cost of existing equipment removal and disposal. For heating and cooling equipment, considers the effects of building shell improvements on fuel costs.		
AE	B-93	Technology Choice	Average equipment efficiency by major fuel, decision type, service, building, and census division.	Calculated variable	Non-lighting, non-ventilation: Btu delivered/Btu consumed (≡ Btu out/Btu in) Lighting: lumens/watt Ventilation: thousand CFM-hours air delivered/thousand Btu consumed
AnnualCostTech	B-64	Technology Choice	Annualized life-cycle cost of a technology per unit of delivered service, by technology class, technology vintage, and consumer risk-adjusted time preference premium. Calculated for each census division and building type during	Calculated variable	Non-lighting, non-ventilation: Constant dollars/(thousand Btu out per hour)/year Lighting: Constant dollars/thousand lumens/year

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			each iteration of each projection year. Incorporates building capacity utilization factor, annualized unit installed capital cost, yearly operating and maintenance cost, annualized fuel costs, projected interest rates, and consumer risk-adjusted time preference premiums. For heating and cooling equipment, considers the effects of building shell improvements on fuel costs. Use limited to stage 1 (fuel choice) decision for least-cost behavior rule segment.		Ventilation: Constant dollars/thousand cf/m
AnnualCostTechAdj	B-65	Technology Choice	Annualized life-cycle cost of a technology per unit of delivered service, by technology class, technology vintage, and consumer risk-adjusted time preference premium. Calculated for each census division and building type during each iteration of each projection year. Incorporates building capacity utilization factor, annualized unit installed capital cost, yearly operating and maintenance cost, annualized fuel costs,	Calculated variable	Non-lighting, non-ventilation: Constant dollars/(thousand Btu out per hour)/year Lighting: Constant dollars/thousand lumens/year Ventilation: Constant dollars/thousand CFM

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			projected interest rates, and consumer risk-adjusted time preference premiums—potentially adjusted for increasing energy prices. For heating and cooling equipment, considers the effects of building shell improvements on fuel costs. Used for stage 2 decision for least-cost behavior rule segment and for same-fuel and same-technology technology choice decisions.		
AverageEfficiency	B-96	Technology Choice	Effective average efficiency of the equipment mix by major fuel, end-use service, building type, and census division for the current year, as calculated in the Technology Choice subroutine.	Calculated variable	Non-lighting, non-ventilation: Btu delivered/Btu consumed (≡Btu out/Btu in) Lighting: lumens/watt Ventilation: thousand CFM-hours air delivered/thousand Btu consumed
AverageEfficiencyBASE	B-13	Service Demand	Effective average efficiency of the equipment mix by major fuel, end-use service, building type, and census division during the CBECS base year, as calculated from the	Calculated variable	Non-lighting, non-ventilation: Btu out/Btu in Lighting: lumens/watt Ventilation:

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			input equipment efficiencies and market shares.		thousand CFM-hours air delivered/thousand Btu consumed
BaseYrPCShrofOffEqEUI	B-8	Service Demand	Proportion of the base-year office equipment EUI present in file KINTENS that is attributable to office computing equipment. If the parameter is assigned a value less than zero, then the EUIs in KINTENS for PCs and non-PCs are used as specified, otherwise the value given in the PCs slot is interpreted to represent total office equipment EUI and is split accordingly.	Input parameter KPARM	Unitless
BehaviorShare	B-77	Technology Choice	Share of commercial consumers following each of the three behavior rules [least-cost (LC), same-fuel (SF), and same-technology (ST)] for new, replacement, and retrofit decision types, by building type, major service, behavior rule, and decision type.	Input from file KBEHAV	Unitless
BrewerFlrBase	B-42	Service Demand	Total food service and small and large office building floorspace with demand for coffee brewers within miscellaneous electric	Calculated variable	Million sq ft

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			loads (MELs) for the current projection year.		
CapacityFactor	B-64	Technology Choice	Equipment capacity utilization factor representing the proportion of time each service is demanded in each building type and census division, averaged over one year.	Input from file KCAPFAC	Unitless
CBECSFlrSpc	B-2	Floorspace	Commercial floorspace by census division, building type, and vintage cohort (see CMVintage), as surveyed by CBECS in the year CBECSyear.	Input from file KFLSPC	Million sq ft
CBECSyear	B-2	COMM	Survey year of CBECS data used as base year for the CDM. Current value is 2018.	Parameter	Calendar year
CforSrestrict	B-10	Service Demand	Total fuel consumption by technology class and vintage, end use, and census division in CBECSyear across building types where the technology is allowed. Used in calculating base-year technology shares of service.	Calculated variable	Billion Btu
CforStotal	B-9	Service Demand	Total fuel consumption by end use and census division in CBECSyear. Used in calculating base-year technology shares of service.	Calculated variable	Billion Btu
CMAvgAge	B-1	Floorspace	Median building lifetime by building type *b*.	Input from file KBLDG	Years

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
CMFinalEndUse	B-129	Consumption	Consumption of fuels across end uses, including CHP and district services, by fuel type (major, minor, and renewable), census division, and year.	Calculated variable	Trillion Btu
CMFinalEndUseCon	B-133	Consumption	U.S. total consumption across end uses, including CHP and district services, by building type and year.	Calculated variable	Trillion Btu
CMFinalUnbenchUse	B-128	Consumption	Unbenchmarked fuel consumption across building types by fuel type, census division, and year.	Calculated variable	Trillion Btu
CMFirstYr	B-51	COMM	Index of first year of projections. Set to the first year after CBECSyear, the year of the CBECS from which the base year data is derived.	Assigned in source code	Unitless index
CMGamma	B-1	Floorspace	Shape parameter of the floorspace survival function, by building type. Describes clustering of building retirements near median lifetime.	Input parameter KBLDG	Unitless
CMNewFloorSpace	B-2	Floorspace	New commercial floorspace construction by census division, building type, and year. Includes backcast estimates of new floorspace during original year of	Calculated variable	Million sq ft

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			construction for years before CBECSyear.		
CMNonBldgUse	B-133	Benchmarking	Non-building fuel consumption by census division, fuel, and year.	Calculated variable	Trillion Btu
CMnumBldg	B-48	Service Demand	Number of CDM building types. Current value is 11.	Parameter	Unitless
CMNumCt	B-52	Service Demand	Number of sensor and control technology types. Current value is 5.	Parameter	Unitless
CMnumMajFl	B-16	Service Demand	Number of CDM major fuels. Current value is 3.	Parameter	Unitless
CMnumVarSDI	B-33	Service Demand	Number of end-use services for which intensity differences between existing and new floorspace have been characterized.	Parameter	Unitless
CMOldestBldgVint	B-3	Floorspace	The median year of construction for buildings in the earliest CBECS age cohort group. Current value is 1901.	Parameter	Calendar year
CMSEDS	B-131	Benchmarking	State Energy Data System (SEDS) historical consumption by census division, fuel, and year for the commercial sector, for the years 1990 through 1989+MSEDYR. Similar data from MER and STEO are present for the years 1989+MSEDYR+1 through 1989+KSTEOYR.	Module input from Global Data Structure and file KSTEO	Trillion Btu
CMSurvRate	B-1	Floorspace	Logistic building survival function, giving the	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			proportion of original construction still surviving as a function of the age, and the parameters CMAvgAge and CMGamma.		
CMTotalFlspc	B-46	Floorspace	Total commercial floorspace in million square feet by census division, building type, and year. Building type CMnumBldg+1 corresponds to sum across building types.	Calculated	Million sq ft
CMUSAvgEff	B-103	Technology Choice	National average equipment efficiency by end-use service, fuel, and projection year.	Calculated variable	Btu delivered/Btu consumed
CMUSConsumption	B-125	Consumption	U.S. total fuel consumption by end use, fuel type, and year.	Calculated variable	Quadrillion Btu
CMUSDistServ	B-121	Consumption	U.S. total fuel consumption to provide district services by end use, fuel type, and year.	Calculated variable	Quadrillion Btu
CMVintage	B-2	Floorspace	The median original year of construction for buildings by census division, building type, and vintage cohort group.	Input from file KVINT	Calendar year
ComEUI	B-7	Service Demand	Base-year energy use intensity (EUI) by fuel type, end-use service, building type, and census division. Base year = CBECSyear.	Input from file KINTENS	Thousand Btu consumed/sq ft/year
ComSTEOBM	B-144	Benchmarking	Flag indicating whether optional benchmarking to STEO is to be	Input from file KPARM	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			performed. A value of one indicates yes; zero indicates no. Must be used in conjunction with NEMS parameter STEOBM.		
CostTrendSwitch	B-60	Technology Choice	Flag indicating whether optional cost trend function is to be used in calculating annualized life-cycle costs. A value of one indicates yes; zero indicates no.	Input from file KPARM	Unitless
CT_Flag	B-52	Service Demand	Flag indicating whether a sensor or control technology has the potential to reduce service demand for a particular end use. A value of one indicates yes; zero indicates no.	Input from file KMELS	Unitless
DatCtrShare	B-30	Service Demand	Share of floorspace representing data centers.	Calculated variable	Unitless
Dcf	B-31	Service Demand	Service demand intensity ratio of buildings with on-premise data centers to buildings without data centers, by end-use service.	Parameter defined in source code	Unitless
DecAvgEff	B-97	Technology Choice	Effective average efficiency of the equipment mix selected to satisfy service demands, by decision segment, census division, major end-use service, major fuel, and projection year.	Calculated variable	Non-lighting, non-ventilation: Btu out/Btu in Lighting: lumens/watt Ventilation: thousand CFM-hours air

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
					delivered/thousand Btu consumed
DecayBM	B-145	Benchmarking	Flag to indicate whether optional benchmarking to STEO is to include taper of final discrepancy with STEO to zero. Value of one indicates yes; zero indicates no.	Input from file KPARM	Unitless
DecFuelShare	B-100	Technology Choice	Fuel share of service, by decision type, census division, major end-use service, major fuel type, and projection year.	Calculated variable	Unitless
DegreeDays	B-112	Consumption	DegreeDays (1,r,y) is the number of heating degree days and DegreeDays (2,r,y) is the number of cooling degree days in census division *r* during year *y*. Historical data and short-term forecast developed by NOAA (see dates in KDEGDAY). Data for subsequent years are based on a 30-year linear trend for heating and cooling degree days, adjusted for projected state population shifts. The data are used to perform a weather adjustment to the consumption projections in the Consumption subroutine and to	Input from KDEGDAY	Degrees Fahrenheit × day

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			determine the relative amounts of heating and cooling supplied by heat pumps (Equation B-80).		
DistServBoilerEff	B-119	Consumption	Efficiency of systems that provide district energy services, by fuel type.	Input from file KDSEFF	Btu out/Btu in
DistServConsump	B-119	Consumption	Consumption of fuels to provide district services, by census division, building type, fuel, year, and district service.	Calculated	Trillion Btu in
DistServFuelShr	B-119	Consumption	Proportions of district service steam energy generated by each fuel type. Dimensions: census division, fuel, and end-use service.	Input from file KDSFS	Unitless
DistServSteamEUI	B-119	Consumption	Steam energy per square foot generated to provide district services by census division, building type, and district service for the three services: space heating, space cooling, and water heating.	Input from file KDSSTM	Thousand Btu out/sq ft/year
EF1	B-110	Consumption	Weight given to ratio of current fuel price relative to base-year fuel price in calculating short-term price elasticity.	Defined in source code	Unitless
EF2	B-110	Consumption	Weight given to ratio of previous year fuel price relative to base-year fuel price in calculating	Defined in source code	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			short-term price elasticity.		
EF3	B-110	Consumption	Weight given to ratio of fuel price from two years previous relative to base-year fuel price in calculating short-term price elasticity.	Defined in source code	Unitless
EffectHurdle	B-63	Technology Choice	Hurdle (implicit discount) rate. The sum of the 10-year Treasury note rate and the risk-adjusted time preference premium, with a 3% floor, for the current major service, risk-adjusted time preference level, and projection year	Calculated variable	Unitless
EffectHurdleAdj	B-63	Technology Choice	Effective hurdle (implicit discount) rate after considering effects of fuel price changes for the current census division, major service, fuel, risk-adjusted time preference level, and projection year.	Calculated variable	Unitless
EffGrowthRate	B-104	Technology Choice	Average annual growth rate of minor service efficiencies.	Module input from KDELEFF	Unitless
ElevatorFlrBase	B-42	Service Demand	Total U.S. floorspace, with demand for elevators within MELs for the current projection year.	Calculated variable	Million sq ft
ElShr	B-114	Consumption	Share of electricity consumption by end use. Used to compute adjustment to account	Computed	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			for self-generation. Dimension: end-use service.		
EndUseConsump	B-108	Consumption	Projected consumption of fuel by end-use service, major fuel, building type, census division, and projection year.	Calculated variable	Trillion Btu
EscalatorFlrBase	B-42	Service Demand	Total U.S. floorspace (excluding food sales, food service, small office, and warehouse), with demand for escalators within MELs for the current projection year.	Calculated variable	Million sq ft
EquipRestriction	B-10	Service Demand	A logical variable (*flag*) indicating whether a technology class and vintage is blocked from use in a certain building type. A value of zero indicates the technology class and vintage is allowed; one indicates it is not allowed.	Input from file KTEKX	Unitless
ExistImprvCl	B-19	Service Demand	Building shell cooling efficiency improvement for existing buildings achieved by the last year of the projection period as a proportion relative to the CBECS base year.	Input from file KSHEFF	Unitless
ExistImprvHt	B-19	Service Demand	Building shell heating efficiency improvement for existing buildings achieved by the last year of the projection period as a proportion	Input from file KSHEFF	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			relative to the CBECS base year.		
ExistShBaseStockCl	B-19	Service Demand	Base year to current year improvement in building shell cooling efficiency for buildings surviving from the base-year floorstock.	Calculated variable	Unitless
ExistShBaseStockHt	B-19	Service Demand	Base year to current year improvement in building shell heating efficiency for buildings surviving from the base-year floorstock.	Calculated variable	Unitless
FinalEndUseCon	B-123	Consumption	Final end-use consumption of major and minor fuels, by census division, building type, fuel, and projection year, summed across services, including district services and CHP.	Calculated variable	Trillion Btu
FirstNonBenchYr	B-147	Benchmarking	Final year of time span over which to taper down the final STEOMistie optionally used in benchmarking. If STEO benchmarking option is selected, and the STEO taper option is selected, then the adjustment for FirstNonBenchYr and future years because of mismatch with STEO during earlier years becomes zero.	Input from file KPARM (into temporary intermediate variable named LastDecayYr)	Calendar year

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
FS	B-92	Technology Choice	Fuel share of service by census division, building type, end-use service, decision type, and major fuel.	Calculated variable	Unitless
FloorAdj	B-127	Consumption	Floorspace adjustment factor by region (McGraw-Hill floorspace/CBECS floorspace)	Calculated variable	Unitless
FuelShareofService	B-94	Technology Choice	Projected fuel share of service demand, by census division, building type, end-use service, and major fuel. Represents value for the previous year, until updated for the current year by the Technology Choice Submodule.	Calculated variable	Unitless
FuelShareofServiceBASE	B-36, B-39	Service Demand	Projected fuel share of service demand, by census division, building type, end-use service, and major fuel, in the CBECS base year	Calculated variable	Unitless
FuelUsage	B-118, B-185	Consumption, Distributed Generation	Accumulated total fuel consumption (if applicable) for all distributed generators. Dimension: year, census division, building type, and technology.	Computed	Trillions of Btu
Gamma	B-60	Technology Choice	Shape parameter corresponding to the rate of price decline in the cost trend function	Input from KTEKX	Unitless
HeatPumpCoolingSD	B-89	Technology Choice	Amount of cooling service demand satisfied by heat pumps	Calculated variable	Trillion Btu out

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			by decision type (new replacement and retrofit).		
HurdleElas	B-63	Technology Choice	Hurdle (implicit discount) rate elasticity parameter by census division, end-use service, and fuel.	Input from file KHURELA	Unitless
HWBtu	B-117, B-186	Consumption, Distributed Generation	Accumulated total water heating Btu provided by distributed resources. Dimension: year, census division, building type, and technology	Computed	Trillions of Btu
IFMAX	B-107	Technology Choice	Maximum number of years a technology's availability can be advanced as a result of increased fuel prices under Price-Induced Technological Change.	Input from KPARM	Number of years
iForward	B-107	Technology Choice	Actual number of years a commercial sector technology's availability is brought forward based on Price-Induced Technological Change. Dimensioned by technology class, vintage, and year.	Calculated variable	Number of years
KElast	B-110	Consumption	Graduated short-term price elasticity function. Elasticity for each major fuel, end-use service, and census division in each year is calculated as a weighted function of the price of the fuel in the current year and the previous two years	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			relative to the base-year fuel price.		
KEqCost	B-60	Technology Choice	Logistic cost trend function, giving the unit installed capital cost of equipment by technology and vintage for the current year. Cost is calculated as a function of the initial unit installed capital cost, the current year, year of curve point of inflection, year of introduction, total anticipated percentage cost decline, and rate of cost decline.	Calculated variable	Non-lighting, non-ventilation: Constant dollars/(thousand Btu out per hour)/year Lighting: Constant dollars/thousand lumens/year Ventilation: Constant dollars/thousand CFM
KitchenFlrBase	B-42	Service Demand	Total floorspace excluding large office, small office, warehouse, and other with demand for kitchen ventilation within MELs for the current projection year	Calculated variable	Million sq ft
Kscale	B-14	Service Demand	The scale factor that is applied to KTEKX market shares of service demand of equipment using each fuel to satisfy demand for the current service in the current building type and census division in the base year. It is calculated in such a way that the fuel shares of consumption implicit in the EUIs from KINTENS are honored for each	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			building type, and it is necessary because the KTEKX market shares are regional and constant across building types, whereas the EUIs vary by building type.		
KSTEOYR	B-134	Benchmarking	Index of last year of STEO data used for benchmarking.	Parameter	Unitless
LaundryFlrBase	B-42	Service Demand	Total mercantile/ service, lodging, and health care floorspace with demand for laundry equipment within MELs for the current projection year.	Calculated variable	Million sq ft
LabFlrBase	B-42	Service Demand	Total education, health care, large and small office, and other floorspace with demand for laboratory equipment within MELs for the current projection year	Calculated variable	Million sq ft
LCMSN	B-71	Technology Choice	Equipment market shares of service within least-cost behavior segment of new decision type, by technology class and model number (t, v).	Calculated variable	Unitless
LCMSR	B-72	Technology Choice	Equipment market shares of service within least-cost behavior segment of replacement decision type, by technology class and model number (t, v).	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
LCMSRet	B-84	Technology Choice	Equipment market shares of service within least-cost behavior segment of retrofit decision type, by technology class and model number (t, v).	Calculated variable	Unitless
MarketPenetrationMels	B-43	Service Demand	Market penetration index by minor service and year for the Miscellaneous Electric Loads.	Input from file KMELS	Unitless
MarketPenetrationSC	B-11	Service Demand	Market penetration index by technology and year for sensors and controls.	Input from file KMELS	Unitless
MarkShar	B-11	Service Demand	KTEKX market share: proportion of each service demand that was satisfied by equipment of a particular technology and vintage within each census division and building type during the base year (CBECSyear).	Input from file KTEKX	Unitless
MC_COMMFLSP	B-46	Annual New Floorspace Growth Rate	NEMS MAM projection of percentage growth in commercial floorspace from previous year, by MAM building type, census division, and projection year.	Input from NEMS Macro-economic Activity Module	Billion sq ft
MC_RMGBLUSREAL	B-63	Technology Choice	Yield on 10-year U.S. Treasury notes by year	Input from NEMS Macroeconomic Activity Module	Percent
MedFlrBase	B-42	Service Demand	Total health care, mercantile/service, and	Calculated variable	Million sq ft

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			small and large office floorspace with demand for other medical imaging equipment within MELs for the current projection year.		
MElsELQ	B-42	Service Demand	Initial consumption for Miscellaneous Electric Loads	Input from kmel	Billion Btu
MinFuelAlpha	B-127	Consumption	The regression intercept used in the calculation of minor fuel consumption, by census division and fuel	Input from file KMINFL	Unitless
MinFuelBeta	B-127	Consumption	Price elasticity parameter used in the calculation of minor fuel consumption, by census division and fuel	Input from file KMINFL	Unitless
MiscElQ	B-44	Service Demand	Service demand for each specific category of electric MEL use in each building type and census division for the current projection year. Represented in the code by separate variables within the MiscElQ common block for each MEL use category.	Calculated variable	Trillion Btu
MS	B-77	Technology Choice	Equipment market shares of service demand by building type, major end-use service, decision type, technology class, and technology vintage (model). MS is calculated separately for each census division and projection year.	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
MSEDYR	B-131	Benchmarking	Index of the final year of available SEDS data.	NEMS parameter	Unitless index
NewImprv	B-26	Service Demand	Building shell efficiency improvement for new buildings achieved by the end of the projection period as a proportion relative to the shell efficiency in the CBECS base year.	Input from file KSHEFF	Unitless
NewServDmd	B-25	Service Demand	Service demand in new commercial floorspace by census division, building type, end-use service, and year. Also referred to as NSD.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM-hours
NewShlAvCl	B-26	Service Demand	Average shell cooling efficiency index for new buildings.	Calculated variable	Unitless
NewShlAvHt	B-26	Service Demand	Average shell heating efficiency index for new buildings.	Calculated variable	Unitless
Normalizer	B-90	Technology Choice	Market share adjustment factor for space cooling equipment other than heat pumps, by decision type.	Calculated variable	Unitless
NSD	B-88	Technology Choice	Service demand in new commercial floorspace by census division, building type, end-use service, and year. Also referred to as NewServDmd.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
					Ventilation: Trillion CFM-hours
OfficeFlrBase	B-42	Service Demand	Total large and small office floorspace within MELs for the current projection year.	Calculated variable	Million sq ft
MC_NP	B-136, B-137	Benchmarking	Projected population by census division and projection year. Used to apportion national projection of electricity use for municipal water services to census divisions.	Input from NEMS Macroeconomic Activity Module	Millions of persons
pctSCSavings	B-54	Service Demand	Indexed energy savings due to the adoption of sensors and control technologies. Savings are indexed to CBECS year.	Input from KMELS	Unitless
PrevYrAverageEfficiency	B-104	Technology Choice	Effective average efficiency of the equipment mix by fuel, end-use service, building type, and census division for the previous year.	Calculated variable	Non-lighting, non-ventilation: Btu out/Btu in Lighting: Lumens/watt Ventilation: CFM-hours air out/Btu in
PrevYrFuelShareofService	B-73	Technology Choice	Projected fuel share of service demand for the previous year, by census division, building type, end-use service, and major fuel.	Calculated variable	Unitless
PrevYrTechShareofService	B-50	Service Demand	Proportion of demand for each service satisfied by equipment	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			of a particular technology and vintage within each census division and building type during the previous year.		
Price	B-106	Technology Choice	Commercial sector national fuel prices, by major fuel and projection year. Used in average price calculation for price-induced technological change.	Input from appropriate NEMS supply sector modules.	Constant 1987 dollars per million Btu
PriceDelta	B-63	Technology Choice	Comparison of current-year to base-year fuel price, by fuel (major) and projection year. Used to determine price-induced technological change.	Calculated variable	Unitless
PriceDelta3	B-106	Technology Choice	Comparison of three-year average fuel price to base-year fuel price, by major fuel and projection year. Used to determine price-induced technological change.	Calculated variable	Unitless
ReplacementFuelShareofService	B-58	Technology Choice	Fuel shares of that portion of service demand requiring replacement as a result of equipment failure, by fuel.	Calculated	Unitless
ReplacementProportion	B-54	Technology Choice	Portion of service demand requiring replacement as a result of equipment failure, by census division, building type, and service.	Calculated	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
ReplacementShareofService	B-57	Technology Choice	Failed equipment shares of that portion of service demand requiring replacement as a result of equipment failure, by technology class and vintage (model).	Calculated	Unitless
RetireServDmd	B-50	Service Demand	Service demand in surviving floorspace that becomes unsatisfied in the current projection year as a result of equipment failure, by census division, building type, end-use service, and year. Same as RSD.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM-hours
RetroCostFract	B-79	Technology Choice	Cost of removing and disposing equipment for each technology and vintage for purposes of retrofitting with other equipment. It is expressed as a proportion to be applied to the installed capital cost to determine the removal component of the retrofitting cost per unit of service demand.	Input from KTEKX	Unitless
RSD	B-88	Technology Choice	Service demand in surviving floorspace that becomes unsatisfied in the current projection year as a result of equipment failure, by census division, building type, end-use service, and	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM-hours

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			year. Same as RetireServDmd.		
SD	B-88	Technology Choice	Service demand by decision type for end-use services of space heating and space cooling, calculated for a particular census division, building type, and year.	Calculated variable	Trillion Btu out
SEDSMistie	B-131	Benchmarking	Difference between historical data on fuel consumption derived from State Energy Data System (SEDS) and the CBECS-based CDM projections by fuel (major and minor) and census division.	Calculated variable	Trillion Btu in
ServDmdExBldg	B-18	Service Demand	Service demand in existing commercial floorspace by census division, building type, end-use service, and year. Includes surviving service demand as well as replacement service demand (see SSD and RSD).	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM-hours
ServDmdIntenBASE	B-16	Service Demand	Amount of demand for a service per square foot of floorspace, by census division, building type, and end-use service, calculated for the base year (CBECSyear) based on the base year EUIs, equipment market shares, and other considerations. Identical	Calculated variable	Non-lighting, non-ventilation: Thousand Btu out/sq ft Lighting: Thousand lumen years out/sq ft Ventilation: Thousand CFM-hrs out/sq ft

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			to the base-year EUIs in the case of minor services because minor service equipment efficiencies are indexed to 1 for the base year.		
ServDmdSurv	B-51	Service Demand	Service demand in existing (in other words, not newly-constructed during each year) commercial floorspace by census division, building type, end-use service, and year that continues to be satisfied by non-failed equipment. Same as SSD.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM-hours
ServicedFlrspcProp	B-33	Service Demand	Proportion of building floorspace that receives end-use service, by building type, service, and whether the buildings are newly-constructed (post-1989) or existing (pre-1990).	Input from KVARSDI	Unitless
SFMSN	B-73	Technology Choice	Equipment market shares of service demand within the same-fuel behavior segment of the new purchase decision type, by technology class and model number (t,v).	Calculated variable	Unitless
SFMSR	B-74	Technology Choice	Equipment market shares of service demand within the same-fuel behavior segment of the replacement purchase decision type, by	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			technology class and model number (t,v).		
SFMSRet	B-85	Technology Choice	Equipment market shares of service demand within the same-fuel behavior segment of the retrofit decision type, by technology class and model number (t,v).	Calculated variable	Unitless
SHBtu	B-117, B-187	Consumption, Distributed Generation	Accumulated total space heating Btu provided by distributed resources. Dimension: year, census division, building type, technology.	Computed	Trillion Btu
ShellEffFactor	B-64	Technology Choice	Heating or cooling building shell efficiency factor for the current census division, building type, and year. ShellEffFactor(1) is the average shell efficiency factor of the total surviving floorspace relative to that of the base year (CBECSyear). ShellEffFactor(2) is the shell efficiency factor of new construction relative to the existing stock in the base year.	Calculated variable	Unitless
ShellCoolFactor	B-22	Service Demand	Shell cooling load factor representing the impacts of improvements to building shell thermal performance on cooling service demand. For building type *b* and	Input from file KSHEFF	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			census division *r*, ShellCoolFactor (b,r,1,curiyr) is the current year average shell cooling factor of the total surviving floorspace relative to that of the base year (CBECSyear). ShellCoolFactor (b,r,2, curiyr) is the shell cooling factor of new construction relative to the existing stock in the base year.		
ShellHeatFactor	B-19	Service Demand	Shell heating load factor representing the impacts of improvements to building shell thermal performance on heating service demand. For building type *b* and census division *r*, ShellHeatFactor (b,r,1,curiyr) is the current year average shell heating factor of the total surviving floorspace relative to that of the base year (CBECSyear). ShellHeatFactor (b,r,2, curiyr) is the shell heating factor of new construction relative to the existing stock in the base year.	Input from file KSHEFF	Unitless
SolarRenewableContrib	B-48	Service Demand	The amount of service demand satisfied by solar energy, by census	Input from file KRENEW	Non-lighting: Trillion Btu out

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			division, solar service, and projection year.		Lighting: Billion lumen years out
SSD	B-88	Service Demand	Service demand in existing (in other words, not newly-constructed during each year) commercial floorspace by census division, building type, end-use service, and year that continues to be satisfied by non-failed equipment. Represents service demand subject to the retrofit decision. Same as ServDmdSurv.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM-hours
STEOBM	B-144	Benchmarking	Flag indicating whether optional benchmarking to STEO is to be performed. A value of one indicates yes; zero indicates no. Must be used in conjunction with commercial parameter ComSTEOBM, input from file KPARM.	NEMS parameter	Unitless
STEOMistie	B-141	Benchmarking	Difference between short-term forecast of fuel consumption given by the *Short-Term Energy Outlook* (STEO), and the CBECS-based CDM projections after benchmarking to SEDS using SEDSMistie, by fuel (major and minor) and census division.	Calculated variable	Trillion Btu in
STEOTieDecayFactor	B-145	Benchmarking	Factor optionally applied to final STEO mistie during	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			subsequent years if optional STEO benchmarking and tapering (see DecayBM) have been selected.		
STMSN	B-75	Technology Choice	Equipment market shares of service demand within the same-technology behavior segment of the new purchase decision type, by technology class and model number (t,v).	Calculated variable	Unitless
STMSR	B-76	Technology Choice	Equipment market shares of service demand within the same-technology behavior segment of the replacement purchase decision type, by technology class and model number (t,v).	Calculated variable	Unitless
STMSRet	B-86	Technology Choice	Equipment market shares of service demand within the same-technology behavior segment of the retrofit decision type, by technology class and model number (t,v).	Calculated variable	Unitless
STRetBehav	B-86	Technology Choice	Flag indicating whether optional retrofitting of equipment is allowed within the same-technology behavior segment of the retrofit decision rule. A value of one indicates yes; zero indicates no.	Input from file KPARM	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
SurvFloorTotal	B-3	Floorspace	Total surviving commercial floorspace by census division, building type, and year.	Calculated variable	Million sq ft
SurvivingFuelShareofService	B-56	Technology Choice	Fuel shares of surviving service demand after adjustment for equipment failure by census division, building type, major service, and major fuel.	Calculated	Unitless
SurvivingShareofService	B-55	Technology Choice	Equipment market shares of surviving service demand after adjustment for equipment failure, by equipment class and equipment vintage (model).	Calculated	Unitless
TechAvailability	B-10	Technology Choice	Year boundaries of availability of equipment for purchase. For technology class *t* and vintage (model) *v*, TechAvailability(r,t,v,1) is the calendar year during which the equipment is first available for purchase in the model. TechAvailability(r,t,v,2) is the last year of equipment availability for purchase. By technology class and vintage (model).	Input from KTEKX	Calendar year
TechbyService	B-50	Technology Choice	Logical *flag* variable constructed for use in determining which technology classes are	Calculated variable (based on KTEKX input)	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			defined for each end-use service, by technology class.		
TechCost	B-59	Technology Choice	Initial equipment cost components by census division, technology class, and vintage. For technology class *t* and vintage *v*, TechCost (r,t,v,1) is the unit installed capital cost of the equipment. TechCost (r,t,v,2) is the annual operating and maintenance cost per unit service demand, not including fuel costs.	Input from KTEKX	Non-lighting, non-ventilation: Constant dollars/(thousand Btu out per hour)/year Lighting: Constant dollars/thousand lumens/year Ventilation: Constant dollars/thousand CFM
TechCRI	B-64		TechCRI is the *color rendering index* that characterizes the relative light quality of modeled lighting technologies. It is an index number based on the spectrum of natural light and assigned an index of 1. Incandescent and halogen light sources are also assigned an index of 1, but fluorescent, high intensity discharge, and solid-state lighting technologies with reduced spectra are assigned prototypical values between .25 and .95.	Input from KTEKX	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
TechEff	B-13	Technology Choice	Efficiencies of specific equipment, including allowance for census division and equipment use for multiple services. Generalized quantity needed to determine fuel consumption when amount of delivered service is known; includes seasonal performance factors, coefficients of performance, and efficacies, as appropriate.	Input from KTEKX	Non-lighting, non-ventilation: Btu delivered/Btu consumed (≡Btu out/Btu in) Lighting: lumens/watt Ventilation: thousand CFM-hours air delivered/thousand Btu consumed
TechLife	B-50	Technology Choice	Median life expectancy of equipment, in years, by technology class and vintage (model).	Input from KTEKX	Years; Unitless where used as exponent
TechShareofService	B-95	Technology Choice	Proportion of each service demand that is satisfied by equipment of a particular technology and vintage within each census division and building type. For each projection year, it represents the market shares for the previous year, until it is recalculated for the current year by the Technology Choice subroutine.	Calculated variable	Unitless
TechShareofServiceBASE	B-11	Service Demand	Proportion of each service demand that was satisfied by equipment of a	Calculated variable	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			particular technology and vintage within each census division and building type during the base year (CBECSyear). Calculated based on KTEKX market shares (MarkShar), building restrictions, base-year EUIs, and other considerations.		
TelecomServicesElQ	B-137, B-139 B-140	Benchmarking	Projected electricity consumption for telecom services in each census division for the current projection year.	Calculated variable	Trillion Btu
TelecomServicesQGrowth	B-139, B-140	Benchmarking	Projected growth in electricity consumption for telecom services from last year of available SEDS data to current projection year in each census division.	Calculated variable	Trillion Btu
TimePrefPrem	B-63	Technology Choice	Consumer risk-adjusted time preference interest rate premium that is applicable to a proportion of the population given by TimePrefProp, by major service, risk-adjusted time preference level, and projection year.	Input from file KPREM	Unitless
TimePrefProp	B-71	Technology Choice	Proportion of consumers who fall into each category of consumer risk-adjusted time preference levels (implicit discount rates). The risk-adjusted time preference premiums	Input from file KPREM	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			applicable to each level are given by TimePrefPrem.		
TotExplicitMiscElQ	B-45	Service Demand	Total service demand for all specific categories of electric miscellaneous electric loads (MELs) in each building type and census division for the current projection year. Represented in the code by separate variables for each MEL use category.	Calculated variable	Trillion Btu
TotFlrNoWhse	B-42	Service Demand	Total U.S. floorspace, excluding warehouses, for use in calculating demand for non-road electric vehicles within MELs for the current projection year.	Calculated variable	Million sq ft
TotNewFS	B-21	Service Demand	Total of new construction from base year to year before current year for each building type and census division. Used in computing average building shell efficiency for all but current year's new construction.	Calculated variable	Million sq ft
Trills	B-115 B-183	Consumption, Distributed Generation	Accumulated total electric generation by all distributed generators. Dimension: year, census division, building type, and technology.	Computed	Trillion Btu
UnBenchedCon	B-124	Consumption	Unbenchmarked fuel consumption by fuel	Calculated variable	Trillion Btu

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			type, census division, building type, and year.		
USMiscElQ	B-43	Service Demand	Total U.S. service demand for each specific category of electric MEL in each projection year. Represented in the code by separate variables for each MEL use category.	Calculated variable	Trillion Btu
WaterServicesElQ	B-136	Benchmarking	Projected electricity consumption for municipal water services in each census division for the current projection year.	Calculated variable	Trillion Btu
WaterServicesQGrowth	B-138	Benchmarking	Projected growth in electricity consumption for municipal water services from last year of available SEDS data to current projection year in each census division.	Calculated variable	Trillion Btu
xplicitmiscshr	B-36, B-39	Service Demand	Share of miscellaneous electric end uses explicitly accounted for in base year by building type	Input from KMELS	Unitless
Xprice	B-66	Technology Choice	Expected fuel prices for the commercial sector, by major fuel, census division, and projection year.	Input from the NEMS Integrating Module or calculated, at user’s option.	Constant 1987 dollars per million Btu (converted to constant technology menu year dollars per million Btu for technology choice calculations)

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
A	B-181	Distributed Generation	Influences how quickly distributed generation penetration approaches the maximum over time. Dimensions: census division, technology	Input from file KGENTK	Unitless
AdjCost	B-148	Distributed Generation	Adjusted capital cost of equipment per kilowatt for emerging technologies subject to learning. Dimensions: technology.	Computed	Constant dollars per kilowatt
AdjCost2	B-149	Distributed Generation	Adjusted learned capital cost of equipment per kilowatt for declining costs as system peak capacity in kW increases. Dimension: technology.	Computed	Constant dollars per kilowatt
AssumedStartYr	B-181	Distributed Generation	Year that a given technology is assumed to have begun penetrating the U.S. market, based on historical data. Dimension: technology.	Specified in comm.f	Unitless
Avail	B-164	Distributed Generation	Percentage of time available (1 – forced outage rate – planned outage rate) applied to typical operating hours. Dimensions: technology and vintage.	Input from file KGENTK	Percent
B	B-181	Distributed Generation	Influences how quickly distributed generation penetration approaches the maximum over time.	Input from file KGENTK	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			Dimensions: census division and technology		
BaseYrFuelCost	B-170	Distributed Generation	Initial year fuel costs for operating the generation technology. Calculated from the fuel price and fuel input net savings from displaced water and space heating.	Computed	Constant dollars
Basis	B-160	Distributed Generation	Portion of generating technology installed capital cost still to be depreciated.	Calculated variable	Nominal dollars
Beta (β)	B-148	Distributed Generation	Parameter controlling shape of the technology learning function. Dimension: technology.	Input from file KGENTK	Unitless
BldgShare	B-182	Distributed Generation	Percentage used to distribute exogenous penetrations across building types. Dimension: building type and technology.	Input from file KGENTK	Percent
BTUWasteHeat	B-167	Distributed Generation	Computed waste heat available for water and space heating (valid only for fuel-consuming generating technologies, currently excludes photovoltaics and wind)	Computed	MMBtu
C	B-181	Distributed Generation	Influences what proportion of maximum possible penetration is achieved by a distributed generation technology.	Input from file KGENTK	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			Dimensions: census division and technology		
C_0	B-148	Distributed Generation	*First of a kind* capital cost for a distributed generation technology.	Input from file KGENTK	Constant dollars
CalcEqCost	B-151, B-152	Distributed Generation	Sum of installation cost per kilowatt plus capital cost per kilowatt multiplied by total system kW. May be adjusted based on learning effects.	Computed	Constant dollars
CalcKW	B-150	Distributed Generation	Calculated system peak capacity in kilowatts. Dimensions: technology.	Computed	kW
CapCost	B-148	Distributed Generation	Capital cost of equipment per kilowatt. Dimensions: technology and vintage. May be adjusted based on technology learning.	Input from file KGENTK	Constant dollars per kilowatt
CBECSAvgSqft	B-150	Distributed Generation	Average square feet of floorspace area. Dimensions: census division, building type, and building size class.	Input from file KGENTK	ft^2
CBECSFlspcCatShare	B-182	Distributed Generation	Floorspace area share within a census division from CBECS. Dimensions: census division, building type, and building size category.	Input from file KGENTK	Percent
Degrad	B-165	Distributed Generation	Degradation of conversion efficiency of technology. Currently applies to photovoltaics at a loss of 0.75% of total output per year. That is, after 20 years, a	Input from file KGENTK	Percent

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			5 kW system would produce only 86% (that is, (1-0.5%)^20) of its rated output of 4.5 kW. Dimensions: technology and vintage.		
Dep	B-159	Distributed Generation	Indicator for allowed depreciation method. Straight line=100; declining balance=150; double-declining balance=200. Dimensions: technology.	Input from file KGENTK	Unitless
Depr	B-158, B-159	Distributed Generation	Computed depreciation amount based on straight-line or accelerated declining balance. Method depends on technology and Dep. Dimension: year.	Computed	Nominal dollars
DownPay	B-152	Distributed Generation	The down payment percentage times the total installed cost for the specific technology and vintage being analyzed	Computed	Constant dollars
DownPayPct	B-152	Distributed Generation	Down payment percentage assumed to apply to loans for distributed generation investment	Input from file KGENTK	Percent
ElecAvgKwh	B-173	Distributed Generation	Average annual electricity usage in kWh from CBECS estimated for a building with average floorspace within the building size category. Dimensions: census division, building	Input from file KGENTK	kWh per year

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			type, and building size category.		
ElEff	B-162	Distributed Generation	Electrical conversion efficiency. Dimensions: technology and vintage.	Input from file KGENTK	Percent
EPRPSPR	B-173	Distributed Generation	The unscaled renewable portfolio standard credit (if applicable) for generated electricity. Dimensions: projection year.	Input from NEMS Electricity Market Module	Million dollars per kWh converted to constant technology menu year dollars
ExogPen	B-182	Distributed Generation	Program-driven cumulative units. Dimensions: census division, technology, and year.	Input from file KGENTK	Number of units
FuelCost	B-171	Distributed Generation	Fuel cost for the technology net of any water and space heating cost savings from using waste heat. Dimension: year.	Computed	Nominal dollars
FuelInput	B-166	Distributed Generation	MMBtu of fuel input by the technology.	Computed	MMBtu
FuelPrice	B-170	Distributed Generation	Commercial sector natural gas or distillate fuel oil prices as appropriate. Dimension: census division, projection year, and fuel	Input from NEMS Natural Gas Market Module and Liquid Fuels	Converted to constant technology menu year dollars per million Btu for

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
				Market Module	cash flow calculations
IntervalYrs	B-175	Distributed Generation	DC-to-AC inverter replacement interval in years for solar photovoltaic systems. Dimensions: technology = 1, vintage.	Input from file KGENTK	Years
inflation	B-171	Distributed Generation	Inflation assumption for converting constant dollar fuel costs and fuel cost savings into current dollars for the cash-flow model to make the flows correspond to the nominal dollar loan payments.	Input from file KGENTK	Percent
InstCost	B-151	Distributed Generation	Installation cost per kW. Dimensions: technology and vintage.	Input from file KGENTK	Constant dollars/kW
IntAmt	B-155	Distributed Generation	Interest paid for the loan in each year of the analysis—determines the tax deduction that can be taken for interest paid. Dimension: year.	Computed	Nominal dollars
IntervalCst	B-175	Distributed Generation	Maintenance cost for solar photovoltaic system inverter replacement. Non-zero only if the cash-flow model year is an inverter replacement year based on the replacement interval for the photovoltaic system vintage. Dimensions: technology = 1, vintage.	Input from file KGENTK	Constant dollars/kW
IntRate	B-153	Distributed Generation	Commercial mortgage rate.	Input from file KGENTK	Percent

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
Invest	B-188	Distributed Generation	Current year investment in distributed resources. Dimension: year, census division, building type, and technology	Computed	Millions of constant technology menu year dollars
Inx	B-180	Distributed Generation	Initial interconnection limitation scalar to account for presence of rules, regulations, and policies that affect utility-grid interconnection of distributed generation. Values range from 0 (closed to interconnection) to 1 (open to interconnection). Dimension: census division.	Input from file KGENTK	Unitless
Inxdecay	B-180	Distributed Generation	Interconnection limitation factor applied to distributed generation penetration. Starts at *Inx.* Assumed to approach 1 (open to interconnection) over time as limitations decrease. Dimensions: year and census division.	Computed	Unitless
Inxfy	B-180	Distributed Generation	Initial year of interval over which interconnection limitations disappear. Set to the latest full historical year.	Input from file KGENTK	Calendar year
Inxly	B-180	Distributed Generation	Last year of interval over which interconnection limitations disappear.	Input from file KGENTK	Calendar year

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			Currently set to the end of the projection period.		
KWH	B-165	Distributed Generation	kWh generated in each of the years of the cash-flow analysis. Defined as annual kWh adjusted for degradation (in other words, if the degradation factor is not equal to zero).	Computed	kWh
LoanBal	B-156	Distributed Generation	Principal balance of the loan for each year of the analysis—used to compute the current year's IntAmt. Dimension: year	Computed	Nominal dollars
LossFac	B-161	Distributed Generation	Conversion losses (for systems that are rated *at the unit* rather than per available alternating current wattage) if appropriate. Dimensions: technology and vintage.	Input from file KGENTK	Percent
MaintCost	B-175	Distributed Generation	The maintenance cost from the input file (for the specific technology and vintage being analyzed), inflated to current year dollars for the cash-flow analysis. Includes inverter replacement at discrete intervals for PV systems. Dimension: year.	Computed	Nominal dollars
MaintCostBase	B-175	Distributed Generation	Annual maintenance cost. Dimensions: technology and year.	Computed	Constant dollars
MaxPen	B-179	Distributed Generation	Computed maximum possible penetration for	Computed	Percent

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			a given distributed technology into eligible floorspace in a given census division, building type and size category, and solar insolation and electricity price niche, as a function of simple payback		
MpS	B-163	Distributed Generation	Estimated average annual wind speed.	Input from file KGENTK	Meters per second
NetCashFlow	B-177	Distributed Generation	Net of costs and returns for the specific technology and vintage being analyzed in the cash-flow analysis. Dimension: year.	Computed	Nominal dollars
NGRateScalar	B-170	Distributed Generation	Niche natural gas price rate scalar. Dimensions: census division, solar insolation niche, and electricity price niche.	Input from file KGENTK	Unitless
OperHours	B-164	Distributed Generation	Operation hours Dimensions: technology.	Input from file KGENTK	Hours
Outlay	B-154	Distributed Generation	Outlays for capital relating to down payments and borrowing costs. Dimension: year.	Calculated	Constant technology menu year dollars
Payment	B-153	Distributed Generation	Computed annual payment using loan amortization formula	Calculated	Constant technology menu year dollars
pctPVSuitable	B-150	Distributed Generation	Percentage of commercial roof area suitable for PV installation. Dimension: building size.	Input from file KGENTK	Percent
PelCMout	B-172	Distributed Generation	Commercial sector electricity prices.	Input from NEMS	Converted to constant

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			Dimensions: census division, projection year, and end-use service.	Electricity Market Module	technology menu year dollars per kilowatthour for cash flow calculations
PelME	B-173	Distributed Generation	Marginal price for utility purchases. Used for calculating the value of electricity sold to the grid. Dimensions: census division and projection year.	Input from NEMS Electricity Market Module	Converted to constant technology menu year dollars per kWh for cash flow calculations
Pen	B-181	Distributed Generation	Computed penetration for a given technology in a given year Dimensions: technology, year, census division, building type, building size category, solar insolation niche, and electricity price niche	Computed	Percent
Prin	B-156	Distributed Generation	The amount of principal paid on the loan in each year of the analysis—used to determine the loan balance for the next year of the analysis. Dimension: year.	Computed	Nominal dollars
RateScalar	B-172	Distributed Generation	Niche electricity price rate scalar. Dimensions: census division, solar insolation niche, and electricity price niche.	Input from file KGENTK	Unitless
RoofAreatoSqftRatio	B-150	Distributed Generation	Roof area per unit of floorspace area. Dimensions: census division, building type, solar insolation niche, and electricity price niche.	Input from file KGENTK	Unitless

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
RPS	B-173	Distributed Generation	Scalar to adjust the renewable portfolio standard credit (if applicable) for generated electricity. Dimension: projection year.	Input from file KGENTK	Unitless
ScaleFac	B-149	Distributed Generation	Parameter determining how quickly costs decline as system peak capacity in kW increases. Dimension: technology.	Input from file KGENTK	Constant dollars/kW
SimplePayback	B-178	Distributed Generation	The equivalent payback year number computed from the internal rate of return (IRR) for use in the penetration function.	Computed	Year index
SqftShare	B-182	Distributed Generation	The floorspace area share within a census division for a specific solar insolation and electricity price niche. Dimensions: census division, solar insolation niche, and electricity price niche.	Input from file KGENTK	Unitless
SolarIns	B-161	Distributed Generation	Solar insolation for photovoltaics. Dimensions: census division, solar insolation niche, and electricity price niche.	Input from file KGENTK	Kilowatthours per square meter per day
SpaceHtgMMBtu	B-169	Distributed Generation	Waste heat available to serve space heating requirements. Nonzero only if total available Btu of waste heat is	Computed	MMBtu per year

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			greater than water heating requirements.		
TaxCredit	B-157	Distributed Generation	Allowed tax credit computed as the minimum of TaxCreditMax and the TaxCreditPct times the total installed cost. The tax credit is limited to $25,000 per year. Dimension: year.	Computed	Nominal dollars
TaxCreditMax	B-157	Distributed Generation	Cap on the total dollar amount of a tax credit (if any). Dimensions: technology and vintage.	Input from file KGENTK	Constant dollars
TaxCreditPct	B-157	Distributed Generation	Percentage applied to installed cost for computing tax credit.	Input from file KGENTK	Unitless
TaxDeduct	B-176	Distributed Generation	Combined tax rate times interest paid in the previous year plus any applicable tax credit. Dimension: year.	Computed	Nominal dollars
TxLife	B-158	Distributed Generation	Tax life of equipment, generally different from useful life. Dimensions: technology and vintage.	Input from file KGENTK	Years
TaxRate	B-176	Distributed Generation	Marginal combined federal and state income tax rate, currently assumed to be 40% for the typical commercial business	Input from file KGENTK	Unitless
Term	B-153	Distributed Generation	Commercial loan term	Input from file KGENTK	Years
TrillsOwnUse	B-184	Distributed Generation	Accumulated total electric generation retained for own use onsite. Dimension: year,	Computed	Trillion Btu

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			census division, building type, and technology.		
Units	B-182	Distributed Generation	Total number of units with distributed generation installed. Dimension: year, census division, building type, and technology.	Computed	Number of units
ValESave	B-174	Distributed Generation	Inflated base-year value of energy savings in nominal dollars for the cash-flow analysis. Dimension: year.	Computed	Nominal dollars
ValESaveBase	B-173	Distributed Generation	Initial value of generated electricity savings to begin the cash-flow model net benefits calculation.	Computed	Constant dollars
WaterHeatingMMBtu	B-168	Distributed Generation	The lesser of 1) average annual water heating required for average size building in each size class (water heating EUI from CBECS * average floorspace) and 2) the available Btu of waste heat estimated from the distributed generation technology. Dimension: building type and size category.	Computed	MMBtu per year
WhRecovery	B-167	Distributed Generation	Waste heat recovery factor for technologies that burn fuel (that is, not photovoltaics or wind). This waste heat can then be made available for water and space heating, which provides additional	Input from file KGENTK	Percent

Input/ output name	Equation number	Subroutine	Definition and dimensions	Classification	Units
			energy cost savings for distributed generation technologies. Dimensions: technology and vintage.		

Profiles of input data

This section provides additional details for the model inputs listed in Table A-1 above. The variable names as they appear in the Fortran code are included along with definitions, classifications, NEMS input file location, longer discussions, and source references.

MODEL INPUT: Proportion of base-year office equipment EUI attributable to PC use

VARIABLE NAME: BaseYrPCShrofOffEqEUI

MODEL COMPONENT: Service Demand

DEFINITION: PC proportion of base-year office equipment EUI

CLASSIFICATION: Input parameter (KPARM)

DISCUSSION:

The CBECS Public Use Files provide end-use consumption estimates by building type, fuel type, and census division for the end-use services modeled by the NEMS CDM, developed using a combination of engineering end-use models and regression approaches. The estimates include separate breakouts for computing equipment and other office equipment, eliminating the need for the PC proportion parameter.

The parameter has been given a value of -1.0 in KPARM to automatically disable its use, triggering use of the specific PC EUI in the EUI input file, KINTENS.

SOURCES:

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Public Use Files, May 2016.

U.S. Energy Information Administration*, 2003 Commercial Buildings Energy Consumption Survey*, Public Use Files, September 2008.

MODEL INPUT: Consumer behavior rule proportions

VARIABLE NAME: BehaviorShare

MODEL COMPONENT: Technology Choice

DEFINITION: Proportions of commercial consumers using the least-cost, same-fuel, and same-technology behavior rules for decision type *d* in building type *b*

CLASSIFICATION: Input from file KBEHAV

DISCUSSION:

These parameters are designed to facilitate model calibration to historical data, so precise specifications are not expected. Nevertheless, professional judgment is applied to estimate initial values for the proportions by decision type and building type, which are consistent with the commercial sector. Building type is used here as a proxy to distinguish different types of commercial sector decision makers, and decision type represents the different economic situations under which technology choice decisions are made.

The judgment estimates are made separately for all government, privately owned, and rented floorspace for the replacement and retrofit decision types. The proportions of floorspace by government, private, and rented space from the *2018 Commercial Buildings Energy Consumption Survey* Public Use Files are used to weight these estimates by building type to yield replacement and retrofit behavior rule proportions by building type. Similarly, judgment estimates are made for self-built and speculative developer floorspace for the new decision type. These judgment estimates consider estimates of the proportions of self-built and speculative developer floorspace for each by building type to yield new building behavior rule proportions by building type.

SOURCES:

Decision Analysis Corporation of Virginia and Leidos (formerly Science Applications International Corporation). *Alternative Methodologies for NEMS Building Sector Model Development*, draft report, prepared under Contract No. DE-AC01-92EI21946, August 3, 1992, p. 14.

Feldman, S. “Why is it So Hard to Sell ‘Savings’ as a Reason for Energy Conservation?” *Energy Efficiency: Perspectives on Individual Behavior*, Willett Kempton and Max Neiman eds., American Council for an Energy-Efficient Economy, Washington, DC, 1987, pp. 27–40.

Komor, P. and L. Wiggins. “Predicting Conservation Choice: Beyond the Cost-Minimization Assumption.” *Energy*, Vol. 13, No. 8, 1988, pp. 633–645.

Komor, P. and R. Katzev. “Behavioral Determinants of Energy Use in Small Commercial Buildings: Implications for Energy Efficiency.” *Energy Systems and Policy*, Vol. 12, 1988, pp. 233–242.

Lamarre, L. “Lighting the Commercial World.” *EPRI Journal*, December 1989, pp. 4–15.

Lamarre, L. “New Push for Energy Efficiency.” *EPRI Journal*, April/May 1990, pp. 4–17.

Office of Technology Assessment. *Building Energy Efficiency*. OTA-E-518, U.S. Government Printing Office, Washington, DC, May 1992.

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, May 2016.

Vine, E. and J. Harris. "Implementing Energy Conservation Programs for New Residential and Commercial Buildings." *Energy Systems and Policy*, Vol. 13, No. 2, 1989, pp. 115–139.

MODEL INPUT: Equipment Capacity Factor

VARIABLE NAME: CapacityFactor

MODEL COMPONENT: Technology Choice

DEFINITION: Capacity factor of equipment to meet service *s* in census division *r* in building type *b*

CLASSIFICATION: Input from file KCAPFAC

DISCUSSION:

The capacity factor is the ratio of actual annual equipment output to output if that equipment were run 100% of the time at full capacity. We develop capacity factors by census division, building type, and major end-use service, and we model them through parametric building energy analysis of DOE's 16 EnergyPlus reference commercial buildings in six weather locations. Lighting capacity factors vary by building type and are based on the ratio of average hours of operation to total hours per reference building schedules, while capacity factors for the remaining services are derived by service and building type from the ratio of operating hours to total hours in the building load profiles. The results for the weather locations are weighted to compute census division-level capacity factors used by the NEMS CDM (Table A-2).

Table A-2. Weather location weights for capacity factor calculations

percentage

Benchmark city	Census division								
	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
Atlanta		25%			75%	75%	100%		
Chicago	80%	75%	100%	75%	25%	25%			
Denver								75%	
Duluth	20%			25%					
Los Angeles								25%	20%
San Francisco									80%

SOURCES:

Leidos. *Commercial Building Capacity Factors for Use in the CDM*, prepared for U.S. Energy Information Administration, June 2013.

MODEL INPUT: Base-year commercial floorspace

VARIABLE NAME: CBECSFlrSpc

MODEL COMPONENT: Floorspace

DEFINITION: Commercial floorspace by building type *b* in census division *r* for base year

CLASSIFICATION: Input from file KFLSPC

DISCUSSION:

A straightforward aggregation of weighted survey data from CBECS was used to compute base-year levels of commercial floorspace for each of the 11 building categories and nine age ranges (*vintage cohorts*—see CMVintage) in each census division. The mapping used to transfer from the CBECS building classifications to the building-type classification scheme used by the NEMS CDM is shown in Table A-3.

Table A-3. NEMS classification plan for building types

NEMS	CBECS
Assembly	Public Assembly Religious Worship
Education	Education
Food Sales	Food Sales
Food Services	Food Services
Health Care	Health Care—Inpatient

NEMS	CBECS
Lodging	Lodging Skilled Nursing Other Residential Care
Office—Large	Office (> 50,000 square feet) Health Care—Outpatient (> 50,000 square feet)
Office—Small	Office (≤50,000 square feet) Health Care—Outpatient (≤50,000 square feet)
Mercantile and Service	Mercantile Service
Warehouse	Refrigerated Warehouse Non-Refrigerated Warehouse
Other	Laboratory Public Order and Safety Vacant Other

SOURCES:

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

U.S. Energy Information Administration, CBECS Building Type Definitions.

MODEL INPUT: Expected building lifetimes

VARIABLE NAME: CMAvgAge

MODEL COMPONENT: Floorspace

DEFINITION: Median building lifetime by building type *b*

CLASSIFICATION: Input from file KBLDG

DISCUSSION:

The sources cited below contributed to the development of estimates of average building lifetimes for the building types considered by the NEMS CDM. Insufficient data addressing median expected commercial building usage lifetimes were available to enable disaggregation to the census-division level; as a result, we developed a characterization at the national level based on the sources cited below.

SOURCES:

Hazilla, M., and R. Kopp. "Systematic Effects of Capital Service Price Definition on Perceptions of Input Substitution." *Journal of Business and Economic Statistics*. April 1986, pp. 209–224.

KEMA-XENERGY Inc., for Northwest Energy Efficiency Alliance, *Final Report Assessment of the Commercial Building Stock in the Pacific Northwest*, Madison, Wisconsin, March 2004.

McGraw-Hill Construction Dodge Annual Starts – non-residential building starts through 2007.

Publicly available information on demolition and construction of sports stadiums.

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Public Use Files, May 2016.

U.S. Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey*, Public Use Files, September 2008.

U.S. Energy Information Administration, *1999 Commercial Buildings Energy Consumption Survey*, Public Use Files, October 2002.

U.S. Energy Information Administration, *1995 Commercial Buildings Energy Consumption Survey*, Public Use Files, February 1998.

U.S. Energy Information Administration, *1992 Commercial Buildings Energy Consumption Survey*, Public Use Files, July 1996.

U.S. Energy Information Administration, *1989 Commercial Buildings Energy Consumption Survey*, Public Use Files, April 1992.

U.S. Energy Information Administration, *Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings 1986*, Public Use Files, September 1988.

MODEL INPUT: Generation of electricity by commercial sector CHP facilities

VARIABLE NAME: CMCogenEl

MODEL COMPONENT: End-Use Consumption

DEFINITION: Projected commercial sector generation by fuel *f* to meet service demand *s* in census division *r*

CLASSIFICATION: Calculated variable after 2018; Input from file KCOGEN through 2018

DISCUSSION:

Historical data for commercial sector North American Industry Classification System (NAICS) codes from Form EIA-860, *Annual Electric Generator Report*, for the years 2019 through 2021 form the basis for projected power generation by CHP plants by fuel and census division. The Form EIA-860 surveys generating facilities of 5 MW or more and generating facilities of 1 MW or more at two different levels of detail (less detail is provided for producers smaller than 5 MW). The database covers only those facilities generating 1 MW or greater that sell power to utilities. Commercial buildings with smaller capacity and those that produce electricity for self-consumption are excluded, so this source is not comprehensive.

For years after 2021, the baseline projections of generation by source fuel are developed in the Distributed Generation and CHP Submodule as described in the text of this documentation report.

SOURCES:

U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*.

MODEL INPUT: Floorspace survival function shape parameter

VARIABLE NAME: CMGamma

MODEL COMPONENT: Floorspace

DEFINITION: Shape parameter for the floorspace survival function

CLASSIFICATION: Input parameter from file KBLDG

DISCUSSION:

CBECS provides data regarding the age distribution of the existing commercial building stock. The NEMS CDM models floorspace retirement using the logistic survival function,

$$Surviving\ Proportion = \frac{1}{1 + \left(\frac{current\ year - building\ vintage\ year}{median\ lifetime}\right)^{CMGamma}}$$

Half the original floorspace constructed during a particular year is modeled as remaining after a period of time equal to the median building lifetime, regardless of the value used for the building survival parameter, CMGamma. As discussed in this report, CMGamma describes the variance of building retirement about the median lifetime and is set for each NEMS building type based on analysis of the building age distributions of the previous five CBECS and the additional sources cited below.

SOURCES:

KEMA-XENERGY Inc., for Northwest Energy Efficiency Alliance, *Final Report Assessment of the Commercial Building Stock in the Pacific Northwest*, Madison, Wisconsin, March 2004.

McGraw-Hill Construction Dodge Annual Starts – non-residential building starts through 2007.

Publicly available information on the construction and demolition of sports stadiums.

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Public Use Files, March 2015.

U.S. Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey*, Public Use Files, September 2008.

U.S. Energy Information Administration, *1999 Commercial Buildings Energy Consumption Survey*, Public Use Files, October 2002.

U.S. Energy Information Administration, *1995 Commercial Buildings Energy Consumption Survey*, Public Use Files, February 1998.

U.S. Energy Information Administration, *1992 Commercial Buildings Energy Consumption Survey*, Public Use Files, July 1996.

U.S. Energy Information Administration, *1989 Commercial Buildings Energy Consumption Survey*, Public Use Files, April 1992.

U.S. Energy Information Administration, *Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings 1986*, Public Use Files, September 1988.

MODEL INPUT: Oldest modeled buildings

VARIABLE NAME: CMOldestBldgVint

MODEL COMPONENT: Floorspace

DEFINITION: Median year of construction for buildings in the earliest CBECS age cohort group

CLASSIFICATION: Input parameter

DISCUSSION:

CBECS building characteristics include the year of building construction. CBECS and the NEMS CDM use ten age categories, referred to as *vintage cohorts*, to aggregate average building characteristics. These age cohorts are discussed in the section documenting CMVintage. The median year of construction for the oldest vintage cohort (pre-1920) was determined to be 1824 during processing of the CBECS data set and is the value currently assigned to the input parameter, CMOldestBldgVint.

SOURCES:

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

MODEL INPUT: Historical fuel consumption

VARIABLE NAME: CMSEDS

MODEL COMPONENT: Consumption

DEFINITION: State Energy Data System (SEDS) historical energy consumption by census division, fuel, and year for the commercial sector

CLASSIFICATION: Module input from Global Data Structure and file KSTEO

DISCUSSION:

The NEMS uses the State Energy Data System (SEDS) historical consumption data as a standard against which the various sectoral module projections are benchmarked during the historical portion of the projection period. The NEMS Integrating Module provides the SEDS data to the NEMS CDM, and this process is more fully described in the *Integrating Module Documentation Report*. These data are supplemented with data from the *Monthly Energy Review* (MER) and commercial sector projections from the *Short-Term Energy Outlook* (STEO). The CDM treats data from the MER as if they were SEDS data, which is very likely to become the actual case.

SOURCES:

U.S. Energy Information Administration, *Monthly Energy Review*, Washington, DC, October 2024.

U.S. Energy Information Administration, *Short-Term Energy Outlook*, Washington, DC, October 2024.

U.S. Energy Information Administration, *State Energy Data System (SEDS): Consumption, Price, and Expenditure Estimates*. Washington, DC, June 2024.

MODEL INPUT: Floorspace vintages

VARIABLE NAME: CMVintage

MODEL COMPONENT: Floorspace

DEFINITION: Median year of construction of commercial floorspace existing in the base year, by building type, census division, and vintage cohort group.

CLASSIFICATION: Input from file KVINT

DISCUSSION:

CBECS provides data on ages and numbers of buildings by building type and census division. These data were processed to obtain estimates of the median year of construction for buildings constructed in each of the following vintage cohort groups:

- Pre-1920
- 1920–1945
- 1946–1959

- 1960–1969
- 1970–1979
- 1980–1989
- 1990–1999
- 2000–2007
- 2008–2012
- 2013–2018

The results vary with building type and census division and are organized for input to the CDM in the KVINT file.

SOURCES:

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

MODEL INPUT: Energy-Use Intensity

VARIABLE NAME: ComEUI

MODEL COMPONENT: Service Demand

DEFINITION: Energy consumed per unit floorspace for service *s* in building type *b* in census division *r* in year *y*, 1,000 Btu consumed per square foot (ft^2).

CLASSIFICATION: Input from file KINTENS

DISCUSSION:

The CBECS public use microdata files provide CBECS-derived end-use consumption estimates by building type, fuel type, and census division for the end-use services modeled by the NEMS CDM, developed using a combination of engineering end-use models and regression approaches. These end-use consumption estimates are divided by CBECS floorspace data to obtain end-use energy use intensity (EUI) estimates with adjustments based on issues found during the verification process for the CBECS end-use consumption estimates. The final adjusted EUI estimates are input to the CDM from the KINTENS input file.

SOURCES:

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

MODEL INPUT: Heating and cooling degree days

VARIABLE NAME: DegreeDays

MODEL COMPONENT: Consumption

DEFINITION: Heating and cooling degree days by census division *r* and year *y*

CLASSIFICATION: Input from file KDEGDAY

DISCUSSION:

DegreeDays (1,r,y) is the number of heating degree days in census division *r* during year *y*, and DegreeDays (2,r,y) is the number of cooling degree days in census division *r* during year *y*. Historical data are available from 1990 through the month the model was last updated. Values for the following year are developed from the most recent National Oceanic and Atmospheric Administration (NOAA) forecast for heating and cooling degree days. Data input for subsequent years are based on a 30-year linear trend for heating and cooling degree days, adjusted for projected state population shifts. The data are used to perform a weather adjustment to the consumption projections in the Consumption subroutine to account for historical and *normal* differences from the base-year weather and to determine the relative amounts of heating and cooling supplied by heat pumps.

SOURCES:

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Historical Climatology Series 5-1*.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *Historical Climatology Series 5-2*.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, population-weighted heating and cooling degree days.

MODEL INPUT: Cost Trend Function Parameters

VARIABLE NAMES: Delta, Gamma, y0, y1

MODEL COMPONENT: Technology Choice

DEFINITION: Technology-specific cost trend parameters (see definitions below)

CLASSIFICATION: Input from file KTEKX

DISCUSSION:

The cost trend function requires specification of the ultimate price reduction as a proportion of initial cost (delta), a shape parameter governing the rate of cost decline (gamma), the initial year of price decline (y_1), and the year of inflection in the price trajectory (y_0). The assumed values are included in the Technology Characterization Menu of the NEMS CDM. These input parameters are based on the sources cited below.

SOURCES:

Guidehouse and Leidos, *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies – Reference Case*, prepared for U.S. Energy Information Administration, March 2022.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies – Reference Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies – Advanced Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case* Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

MODEL INPUT: District service system efficiencies

VARIABLE NAME: DistServBoilerEff

MODEL COMPONENT: Service Demand

DEFINITION: Efficiency of systems that provide district energy services

CLASSIFICATION: Input from file KDSEFF

DISCUSSION:

National average values for typical boiler efficiencies in converting the fuels of electricity, natural gas, and distillate fuel oil to the intermediate products of steam, hot water, and chilled water plus distribution losses. Values were estimated from data provided in *U.S. District Energy Services Market Characterization: Commercial Data Analysis for EIA's National Energy Modeling System (NEMS)*.

SOURCES:

ICF International and International District Energy Association*, U.S. District Energy Services Market Characterization: Commercial Data Analysis for EIA's National Energy Modeling System (NEMS)*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, Arlington, VA, January 2018.

MODEL INPUT: District service fuel shares

VARIABLE NAME: DistServFuelShr

MODEL COMPONENT: Service Demand

DEFINITION: Proportions of district service steam energy generated by each fuel type

CLASSIFICATION: Input from file KDSFS

DISCUSSION:

These shares are based on fuel consumption of district system plants that generate the intermediate products of steam, hot water, and chilled water. They are estimated from data provided in the *U.S. District Energy Services Market Characterization: Commercial Data Analysis for EIA's National Energy Modeling System (NEMS)*. The fuel share estimates are input to the NEMS CDM from the file KDSFS by fuel, census division, and end-use service.

SOURCES:

ICF International and International District Energy Association*, U.S. District Energy Services Market Characterization: Commercial Data Analysis for EIA's National Energy Modeling System (NEMS)*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, Arlington, VA, January 2018.

MODEL INPUT: District service steam EUIs

VARIABLE NAME: DistServSteamEUI

MODEL COMPONENT: Service Demand

DEFINITION: Steam energy per square foot (thousand British thermal units per square foot) generated to provide district services
(space heating, space cooling, water heating), by census division, building type, and district service

CLASSIFICATION: Input from file KDSSTM

DISCUSSION:

We developed steam EUI estimates using the 2018 CBECS data set similar to how we developed EUI estimates for other end uses. The steam EUI values are totals by building type and census division, and they are not broken down by generating fuel.

SOURCES:

ICF International and International District Energy Association*, U.S. District Energy Services Market Characterization: Commercial Data Analysis for EIA's National Energy Modeling System (NEMS)*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, Arlington, VA, January 2018.

U.S. Energy Information Administration, 2018 Commercial Buildings Energy Consumption Survey, Public Use Files, December 2022.

MODEL INPUT: Minor service equipment efficiency annual growth rate

VARIABLE NAME: EffGrowthRate

MODEL COMPONENT: Technology Choice

DEFINITION: Annual efficiency improvement factor for the minor services of office equipment: PCs, office equipment: non-PC, and miscellaneous end-use loads (MELs).

CLASSIFICATION: Input from file KDELEFF

DISCUSSION:

The user can provide optional efficiency improvement factors for any of the minor services. The annual improvement factor is obtained by calculating the annual percentage improvement in the equipment stock that must be attained to reach the target energy efficiency improvement for the entire stock by the end of the projection period. Changes in energy consumption for PCs, non-PC office equipment, and specific categories within MELs are now explicitly accounted for in the projections described under Market Penetration. Efficiency improvement for the non-specific portions of MELs is set to zero because of a lack of information. Thus the entries in KDELEFF are currently set to zero.

SOURCES:

Not applicable.

MODEL INPUT: Price elasticity of consumer hurdle (implicit discount) rate

VARIABLE NAME: HurdleElas

MODEL COMPONENT: Technology Choice

DEFINITION: Price elasticity parameter (change in consumer hurdle rate as result of change in energy price) by census division *r*, service *s*, and fuel *f* for the major fuels of electricity, natural gas, and distillate fuel oil.

CLASSIFICATION: Input from file KHURELA

DISCUSSION:

This parameter is the exponential term in a logistic function relating the current year fuel price to the base-year fuel price. The parameter is based on user input and is allowed to vary by census division, end-use service, and major fuel. Current parameter values are based on analyst judgment.

SOURCES:

Not applicable.

MODEL INPUT: Maximum number of years for shift in technology availability

VARIABLE NAME: IFMAX

MODEL COMPONENT: Technology Choice

DEFINITION: Price-Induced Technological Change parameter (change in technology availability as result of change in energy price) governing the maximum number of years a technology's availability can be shifted forward.

CLASSIFICATION: Input from file KPARM

DISCUSSION:

This parameter is the maximum number of years that a technology's availability can potentially be advanced based on increasing fuel prices relative to the base-year fuel price. The parameter is based on user input. Current parameter values are based on analyst judgment.

SOURCES:

Not applicable.

MODEL INPUT: Office equipment penetration

VARIABLE NAME: MarketPenetrationMels

MODEL COMPONENT: Service Demand

DEFINITION: Computers, office equipment, and select miscellaneous electric load (MEL) market penetration index by building type and year

CLASSIFICATION: Input from file KMELS

DISCUSSION:

The energy consumption projections for computers, office equipment, IT equipment, data center servers, and additional miscellaneous electric loads (MELs) are based on a 2013 study and a 2021 update to the study completed by Guidehouse, Inc. and Leidos, Inc.. The market penetration index is set to unity in the base year and increases based on projected consumption. The indexed projections of office equipment market penetration are included in the NEMS CDM calculation of service demand. MarketPenetrationMels applies only to the non-specific portions of MELs.

For AEO2022 onward, energy consumption projections for MELs explicitly include point-of-sale systems, warehouse robots, and televisions.

SOURCES:

Arthur D. Little, Inc., *Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings Volume I: Energy Consumption Baseline*, ADL reference 72895-00, prepared for U.S. Department of Energy, Contract No. DE-AC01-96CE23798, January 2002.

Guidehouse, Inc. and Leidos, Inc., *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, prepared for the U.S. Energy Information Administration, April 2021.

Kawamoto, K., J.G. Koomey, B. Nordman, R.E. Brown, M. Piette, M. Ting, A.K. Meier. *Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendices*. LBNL-45917. Prepared by Lawrence Berkeley National Laboratory for the U.S. Department of Energy, February 2001.

Koomey, J.G., *Estimating Total Power Consumption by Servers in the U.S. and the World*, Stanford University, February 2007.

Koomey, J.G., *Growth in Data Center Electricity Use 2005 to 2010*, Stanford University, August 2011.

Navigant Consulting, Inc., and Leidos (formerly Science Applications International Corporation), *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, May 2013.

Navigant Consulting, Inc., and Leidos, *Analysis of Commercial Miscellaneous Electric Loads – 2017 Update*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, April 2017.

Roberson, J.A., R.E. Brown, B. Nordman, C.A. Webber, G.K. Homan, A. Mahajan, M. McWhinne, J.G. Koomey. "Power Levels in Office Equipment: Measurements of New Monitors and Personal Computers," Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings, pp. 7.187-7.199, August 2002.

Silicon Valley Leadership Group, *Data Center Energy Forecast Final Report*, July 2008.

TIAX LLC, *Residential Information Technology Energy Consumption in 2005 and 2010*, Reference No. D0295, prepared for U.S. Department of Energy, U.S. Energy Information Administration, March 2006.

U.S. Energy Information Administration, 2018 Commercial Buildings Energy Consumption Survey, Public Use Files, December 2022.

U.S. Energy Information Administration, *Updated Buildings Sector Appliance and Equipment Costs and Efficiency*. Washington, DC, June 2018.

U.S. Environmental Protection Agency ENERGY STAR Program, Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431, August 2007.

MODEL INPUT: Building sensors and control equipment penetration

VARIABLE NAME: MarketPenetrationSC

MODEL COMPONENT: Service Demand

DEFINITION: Lighting and heating, ventilation, and air-conditioning (HVAC) controls, building energy management systems (BEMS), automated fault detection and diagnosis devices (AFDD), and sub-meters market penetration, indexed to the CBECS base year by building type and year

CLASSIFICATION: Input from file KMELS

DISCUSSION:

The energy savings projections for lighting and HVAC controls, BEMS software, AFDD, and sub-meters are based on a 2020 study completed by Navigant, Inc. and Leidos, Inc.

The projections of equipment market penetration and related energy savings are included in the NEMS CDM calculation of service demand. Energy savings are indexed to the CBECS base year, and estimated for 2012, 2018, 2020, 2030, 2040, and 2050. The model interpolates the market penetration of sensor and control technologies, by year, for years not explicitly characterized in the report.

The effects of the individual technologies depend on the market penetration in a particular year relative to the market penetration in the CBECS base year.

SOURCES:

Leidos, Inc., *Trends in Commercial Whole-Building Sensors and Controls*, prepared for U.S. Energy Information Administration, December 2020.

MODEL INPUT: Base-year equipment market share

VARIABLE NAME: MarkShar

MODEL COMPONENT: Technology Choice

DEFINITION: Market share of technology *k* of vintage *v* that meets service demand *s* in building type *b* in census division *r*.

CLASSIFICATION: Input from file KTEKX

DISCUSSION:

We compute initial base-year market shares for the representative technologies included in the technology characterization database based primarily on technology saturation patterns from CBECS. The computed shares represent the proportion of *demand* that is satisfied by the particular technology characterized by building type for ventilation, refrigeration, and lighting services and by census division for the other major services. Proportions of floorspace serviced by each alternative technology are used as proxies for the market shares of demand where actual market share data is unavailable. We compute these shares for equipment supplying the major services of space heating, space cooling, water heating, ventilation, cooking, lighting, and refrigeration. Additional sources referenced below provided further breakdown of the overall market shares for certain technology classes developed from CBECS.

SOURCES:

Huang et al., *481 Prototypical Commercial Buildings for Twenty Urban Market Areas*, Lawrence Berkeley Laboratory, June 1990.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case* Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

U.S. Energy Information Administration, 2018 Commercial Buildings Energy Consumption Survey, Public Use Files, December 2022.

MODEL INPUT: Minor fuel consumption parameters

VARIABLE NAMES: MinFuelAlpha, MinFuelBeta

MODEL COMPONENT: Consumption

DEFINITION: Parameters used in the calculation of minor fuel consumption

CLASSIFICATION: Input from file KMINFL

DISCUSSION:

MinFuelAlpha and MinFuelBeta are used as follows:

$$FinalEndUseCon_{f.b.r.y} = e^{\left(MinFuelAlpha_{f,r} + \log(price) \times MinFuelBeta_{f.r}\right)}$$

$$\times\ 10^3$$

$$\times \left(SurvFloorTotal_{f,b,r,y} + CMNewFloorSpace_{r,b,y}\right),$$

$$\forall f \in \{MinFuels\}$$

where FinalEndUseCon is final end-use minor fuel consumption. Minor fuel final end-use consumption is measured in trillion Btu for $f \in$ {residual fuel oil, propane, steam coal, motor gasoline, kerosene} for census division *r,* building type *b,* and year *y*, and it is calculated for all projection years from historical census division-level consumption, floorspace, and pricing data using double-log regression equations. MinFuelAlpha and MinFuelBeta are estimated from regressing minor fuel consumption per square foot of commercial floorspace (intensity) on real own price (2012) using the historical data on minor fuel consumption and prices from 1960 to 2022 provided by SEDS publications and the Dodge Data & Analytics floorspace database, and the NEMS projected floorspace. For projection of final end-use consumption, prices are computed in real/constant dollars.

SOURCES:

Dodge Data & Analytics estimated building stock quarterly data and near-term forecasts, 2021 .

Energy Information Administration, "State Energy Data Report: Consumption, price, expenditure, and production estimates, 1960-2022," DOE/EIA-0214(90), Washington DC, June 2024.

Energy Information Administration, "State Energy Data Report: Codes and descriptions, 1960-2022," DOE/EIA-0214(90), Washington DC, June 2024.

U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Public Use Files, May 2016.

U.S. Energy Information Administration, 2018 Commercial Buildings Energy Consumption Survey, Public Use Files, December 2022.

MODEL INPUT: Specific miscellaneous electric load (MEL) indexes

VARIABLE NAMES: MarketPenetrationMels, MelsElQ

MODEL COMPONENT: Service Demand

DEFINITION: Projected consumption trends in specific electricity use categories within MELs

CLASSIFICATION: Input from file KMELS

DISCUSSION:

Service demands projections for specific electricity use categories within MELs are based on electricity consumption estimates and projected national-level trends from studies completed by TIAX LLC, Navigant Consulting, and Leidos. Initial consumption and indexes are fitted to the trends to describe the projected end-use service demand intensity (SDI) for each of the categories. The resulting SDI is multiplied by the appropriate floorspace to obtain service demand. Projected electricity use for transformers is dependent on commercial electricity demand instead of floorspace. Projected electricity use for municipal water services is included in the calculation of non-building energy consumption in the Benchmarking subroutine and is dependent on projected population growth instead of floorspace. The coefficients for the polynomial equations are in units of billion Btu and are provided in Table A-4.

Table A-4. Miscellaneous electric use category equation coefficients

Year	Distribution transformers	Kitchen ventilation	Security systems	Lab fridges and freezers	Medical imaging equipment	Large format video boards	Coffee brewers	Electric vehicles	Fume hoods	Laundry	Elevators	Escalators
2019	0.99	0.98	1.01	0.95	1.01	0.89	1.02	1.10	0.98	0.92	0.99	1.25
2020	0.97	0.96	1.02	0.91	1.01	0.88	1.02	1.12	0.96	0.91	0.98	1.27
2021	0.95	0.94	1.02	0.87	1.02	0.87	1.02	1.13	0.95	0.90	0.97	1.29
2022	0.94	0.92	1.03	0.83	1.03	0.86	1.02	1.15	0.93	0.89	0.96	1.30
2023	0.92	0.90	1.04	0.79	1.04	0.85	1.02	1.16	0.91	0.88	0.96	1.30
2024	0.91	0.88	1.04	0.76	1.04	0.83	1.02	1.18	0.90	0.87	0.95	1.31
2025	0.89	0.86	1.04	0.72	1.05	0.82	1.02	1.19	0.88	0.86	0.94	1.31
2026	0.88	0.84	1.05	0.69	1.05	0.81	1.02	1.21	0.86	0.84	0.93	1.30
2027	0.86	0.82	1.05	0.66	1.06	0.81	1.02	1.22	0.85	0.83	0.92	1.29
2028	0.85	0.80	1.05	0.63	1.06	0.80	1.02	1.24	0.83	0.82	0.91	1.28
2029	0.83	0.78	1.05	0.60	1.07	0.79	1.03	1.25	0.82	0.81	0.90	1.27
2030	0.82	0.76	1.05	0.58	1.07	0.78	1.03	1.26	0.80	0.81	0.89	1.25
2031	0.80	0.74	1.05	0.55	1.07	0.77	1.03	1.28	0.78	0.80	0.88	1.23
2032	0.78	0.73	1.05	0.53	1.08	0.76	1.03	1.29	0.77	0.79	0.87	1.20
2033	0.77	0.71	1.05	0.51	1.08	0.75	1.03	1.30	0.75	0.78	0.87	1.17
2034	0.76	0.69	1.05	0.49	1.09	0.74	1.04	1.31	0.74	0.77	0.86	1.14
2035	0.74	0.68	1.05	0.47	1.09	0.73	1.04	1.32	0.72	0.76	0.85	1.11
2036	0.73	0.66	1.05	0.45	1.10	0.73	1.04	1.32	0.71	0.75	0.84	1.07
2037	0.72	0.65	1.05	0.44	1.10	0.72	1.05	1.33	0.70	0.74	0.84	1.03
2038	0.71	0.63	1.05	0.42	1.11	0.71	1.05	1.34	0.69	0.73	0.83	0.99
2039	0.70	0.62	1.05	0.41	1.12	0.70	1.06	1.34	0.68	0.73	0.83	0.95
2040	0.70	0.61	1.05	0.40	1.13	0.69	1.06	1.35	0.67	0.72	0.82	0.90
2041	0.69	0.60	1.05	0.39	1.14	0.68	1.07	1.35	0.66	0.71	0.82	0.85
2042	0.68	0.59	1.05	0.38	1.15	0.67	1.07	1.35	0.65	0.70	0.81	0.80
2043	0.68	0.57	1.05	0.37	1.16	0.66	1.08	1.35	0.64	0.69	0.81	0.75
2044	0.67	0.56	1.05	0.36	1.17	0.65	1.09	1.35	0.63	0.69	0.80	0.69
2045	0.67	0.55	1.05	0.36	1.18	0.63	1.10	1.34	0.62	0.68	0.80	0.63
2046	0.66	0.54	1.05	0.35	1.18	0.62	1.11	1.34	0.61	0.67	0.79	0.58
2047	0.66	0.53	1.05	0.35	1.19	0.61	1.12	1.33	0.60	0.67	0.79	0.51
2048	0.66	0.52	1.05	0.34	1.20	0.59	1.13	1.32	0.59	0.66	0.78	0.45
2049	0.65	0.51	1.05	0.34	1.21	0.58	1.14	1.31	0.58	0.65	0.77	0.39
2050	0.65	0.50	1.05	0.33	1.23	0.56	1.15	1.30	0.57	0.65	0.77	0.32

Table A-4. Miscellaneous electric use category equation coefficients (continued)

Year	IT equipment	Uninterruptible power supplies (UPS)	UPS: data centers	Shredders	Private branch exchange	Voice over IP	Point-of-sale systems	Warehouse robots	Televisions
2019	1.03	1.36	1.41	0.83	0.39	1.20	0.99	1.19	0.97
2020	1.06	1.40	1.46	0.81	0.33	1.21	0.98	1.37	0.95
2021	1.10	1.44	1.50	0.78	0.28	1.21	0.97	1.55	0.92
2022	1.14	1.47	1.54	0.76	0.23	1.21	0.96	1.71	0.89
2023	1.19	1.50	1.57	0.73	0.19	1.21	0.95	1.87	0.86
2024	1.23	1.53	1.61	0.70	0.15	1.20	0.94	2.03	0.83
2025	1.28	1.55	1.64	0.68	0.12	1.19	0.93	2.18	0.80
2026	1.33	1.58	1.67	0.65	0.10	1.18	0.92	2.33	0.77
2027	1.38	1.60	1.69	0.63	0.08	1.17	0.91	2.46	0.74
2028	1.43	1.61	1.71	0.60	0.06	1.15	0.90	2.59	0.71
2029	1.49	1.63	1.73	0.58	0.05	1.13	0.89	2.71	0.68
2030	1.54	1.64	1.75	0.55	0.04	1.11	0.88	2.81	0.65
2031	1.59	1.65	1.77	0.53	0.03	1.08	0.87	2.91	0.62
2032	1.65	1.66	1.78	0.51	0.02	1.06	0.86	2.99	0.59
2033	1.70	1.67	1.79	0.48	0.02	1.03	0.85	3.07	0.56
2034	1.76	1.67	1.80	0.46	0.02	1.01	0.84	3.14	0.54
2035	1.82	1.68	1.81	0.44	0.02	0.98	0.83	3.20	0.51
2036	1.88	1.68	1.81	0.42	0.02	0.95	0.82	3.25	0.49
2037	1.94	1.68	1.82	0.40	0.03	0.93	0.81	3.30	0.47
2038	2.00	1.67	1.82	0.39	0.03	0.90	0.80	3.34	0.45
2039	2.06	1.67	1.82	0.37	0.03	0.87	0.79	3.36	0.43
2040	2.12	1.67	1.82	0.36	0.00	0.85	0.79	3.38	0.42
2041	2.18	1.66	1.81	0.34	0.00	0.82	0.78	3.39	0.40
2042	2.24	1.65	1.81	0.33	0.00	0.80	0.77	3.39	0.39
2043	2.30	1.64	1.80	0.32	0.00	0.78	0.76	3.39	0.38
2044	2.36	1.63	1.80	0.31	0.00	0.76	0.76	3.39	0.37
2045	2.41	1.62	1.79	0.30	0.00	0.75	0.75	3.39	0.36
2046	2.47	1.61	1.78	0.30	0.00	0.73	0.74	3.39	0.36
2047	2.52	1.60	1.77	0.30	0.00	0.72	0.73	3.39	0.36
2048	2.58	1.59	1.76	0.29	0.00	0.71	0.73	3.39	0.36
2049	2.63	1.57	1.75	0.29	0.00	0.71	0.72	3.39	0.36
2050	2.67	1.56	1.73	0.30	0.00	0.71	0.71	3.39	0.36

SOURCES:

Guidehouse, Inc. and Leidos, Inc., *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, prepared for the U.S. Energy Information Administration, April 2021.

Navigant Consulting, Inc., and Leidos, *Analysis of Commercial Miscellaneous Electric Loads – 2017 Update*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, April 2017.

Navigant Consulting, Inc., and Leidos (formerly Science Applications International Corporation), *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, May 2013.

TIAX LLC, *Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, September 2006.

TIAX LLC, *Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type*, prepared for U.S. Department of Energy, Building Technologies Program, May 2010.

MODEL INPUT: Retrofit removal and disposal cost

VARIABLE NAME: RetroCostFract

MODEL COMPONENT: Technology Choice

DEFINITION: Cost of removing and disposing equipment of each technology and vintage for purposes of retrofitting with other equipment

CLASSIFICATION: Input from KTEKX

DISCUSSION:

The cost is expressed as a proportion to be applied to the installed capital cost. Currently, we use a placeholder value of 1.0 throughout the CDM, pending acquisition and analysis of appropriate data.

SOURCES:

U.S. Energy Information Administration, estimated value.

MODEL INPUT: Serviced floorspace variation with building vintage

VARIABLE NAME: ServicedFlspcProp

MODEL COMPONENT: Service Demand

DEFINITION: Proportion of building floorspace that receives end-use service, by building type, service, and whether the buildings are newly constructed (post-1989) or existing (pre-1990).

CLASSIFICATION: Input from file KVARSDI

DISCUSSION:

An investigation found a measurable difference in demand for different end-use services between *older* and *newer* buildings. For this characterization, *new* was defined as floorspace constructed after 1989. The NEMS CDM parameters characterizing service demand patterns are derived by considering the entire floorspace stock as sampled by CBECS 92, and they are influenced most heavily by values corresponding to the *old* floorspace category. To account for service demand differences in new floorspace construction, the model makes use of the different serviced floorspace proportions, as described in the text of the model documentation. The values were derived by processing the individual CBECS records.

SOURCES:

U.S. Energy Information Administration, *1992 Commercial Buildings Energy Consumption Survey*, Public Use Files, July 1996.

MODEL INPUT: Building shell heating and cooling load factors

VARIABLE NAMES: ShellCoolFactor, ShellHeatFactor

MODEL COMPONENT: Service Demand

DEFINITION: Shell heating and cooling load factors for buildings constructed in the current year for building type *b* in census division *r* in year *y*.

CLASSIFICATION: Input from file KSHEFF

DISCUSSION:

The base-year existing stock shell load factors are indexed to 1.0 for each building type. The building shell load factors for new construction represent the impacts on heating and cooling service demand as a result of improvements in the thermal performance of the building shell of newly-constructed floorspace that must by law adhere to building codes and the general improvement that results from the continual introduction of more shell-efficient new construction.

Regional heating and cooling load factors that reflect current building codes and construction practices relative to the existing building stock in the base year were developed from an ICF International study conducted for EIA. An earlier Leidos study developed overall building U-values for the DOE Building Technology program’s set of reference commercial buildings, adjusted those U-values to correspond to the NEMS building categories and climate regions, and developed *stock* and *new* building U-values and thermal indexes from the adjusted U-values. The study used parametric analysis to develop heating and cooling load factors based on the U-values. The shell characteristics of the benchmark buildings are available for three vintages of buildings: Pre-1980, Post-1980, and New Construction. The New Construction category is based on AHRAE 90.1-2004. The *stock* U-values were developed by weighting the Pre-1980 and Post-1980 characteristics using the CBECS building population.

SOURCES:

ICF International, L.L.C. *Development of Commercial Building Shell Heating and Cooling Load Factors*, prepared for the U.S. Energy Information Administration, February 2018.

Leidos (formerly Science Applications International Corporation), *Thermal Efficiency Indicators Characterizing Existing Commercial Buildings*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, December 2008.

Leidos (formerly Science Applications International Corporation), *Data Analysis for Enhanced Representation of Commercial Thermal Shell Efficiency in the Commercial Demand Module*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, May 2010.

Leidos (formerly Science Applications International Corporation), *Model Documentation of Enhanced Representation of Commercial Thermal Shell Efficiency in the Commercial Demand Module*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, April 2010.

U.S. Energy Information Administration, 2018 Commercial Buildings Energy Consumption Survey, Public Use Files, December 2022.

U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Public Use Files, May 2016.

MODEL INPUT: Short-term price elasticity of service demand

VARIABLE NAME: ShortRunPriceElasofDmd

MODEL COMPONENT: Service Demand

DEFINITION: Short run price elasticity (percentage change in service demand as a result of percentage change in energy price), by service demand *s*, for the major fuels of electricity, natural gas, and distillate fuel oil. This short run price elasticity is a composite factor based on fuel proportions of service demand by census division and service.

CLASSIFICATION: Input from file KSDELA

DISCUSSION:

Table A-5 summarizes a literature review encompassing price response analyses of major fuel demands. Composite price elasticity of service demand estimates based on these sources are included. Input values for the fuel and end-use specific elasticity parameters included in the module are Office of Energy Analysis estimates developed from within the range of empirical values in Table A-5.

SOURCES:

Al-Sahlawi, M., “The Demand for Natural Gas: A Survey of Price and Income Elasticities," *The Energy Journal*, vol. 10, no. 1, January 1989.

Balestra, T. and M. Nerlove, “Pooling Cross-Section and Time-Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas,” *Econometrica*, vol. 34, no. 3, July 1966.

Beierlin, J., J. Dunn, and J. McConnor, Jr., "The Demand for Electricity and Natural Gas in the Northeastern United States," *Review of Economics and Statistics*, vol. 64, 1981.

Berndt, E. and G. Watkins, “Demand for Natural Gas: Residential and Commercial Markets in Ontario and British Columbia,” *Canadian Journal of Economics*, vol. 10, February 1977.

Chern, W. and R. Just, “Assessing the Need for Power: A Regional Econometric Model,” *Energy Economics*, vol. 10, no. 3, 1982, pp. 232–239.

Federal Energy Administration, *1976 National Energy Outlook*, Washington, DC, 1976.

Griffin, J., *Energy Consumption in the OECD: 1880-2000*, Cambridge, Mass., Ballinger Publishing Company, 1979.

Halvorsen, R., “Demand for Electric Energy in the United States,” *Southern Economic Journal*, vol. 42, no. 4, 1975, pp. 610–625.

Joskow, P. and M. Baughman, “The Future of the U.S. Nuclear Energy Industry,” *Bell Journal of Economics*, vol. 7, Spring 1976.

McFadden, D. and C. Puig, *Economic Impact of Water Pollution Control on the Steam Electric Industry*, Chapter 3, Report EED-12, Teknekron Inc., Berkeley, California, 1975.

Mount, T., L. Chapman & T. Tyrrell, *Electricity Demand in the United States: An Econometric Analysis*, National Technical Information Service No. ORNL-NSF-EP-49, Springfield, Virginia, 1973.

Murray, M., R. Spann, L. Pulley, & E. Beauvais, “The Demand for Electricity in Virginia,” *The Review of Economics and Statistics*, vol. 60, no. 4, 1976, pp. 585–660.

Nelson, J., “The Demand for Space Heating Energy,” *Review of Economics and Statistics*, November 1975, pp.508–512.

Uri, N., *A Dynamic Demand Analysis for Electrical Energy by Class of Consumer*, Working Paper No. 34, Bureau of Labor Statistics, January 1975.

Westley, G., *The Demand for Electricity in Latin America: A Survey and Analysis*, Economic and Social Development Department, Country Studies Division, Methodology Unit, Washington, DC, February 1989.

Table A-5. Range of demand elasticity from the literature

				Price elasticities		Income elasticities	
Author	**Sector**	**Time period**	**Fuel**	**Short-run**	**Long-run**	**Short-run**	**Long-run**
Balestra & Nerlove (1966)	Residential-Commercial	1957–62	Natural gas		-0.63		0.62
Joskow & Baughman (1976)	Residential-Commercial	1968–72	Natural gas	-0.15	-1.01	0.08	0.52
Fuss, Hydman & Waverman (1977)	Commercial	1960–71	Natural gas		-0.72		
Berndt & Watkins (1977)	Residential-Commercial	1959–74	Natural gas	-0.15	-0.68	0.04	0.133
Griffin (1979)	Commercial	1960–72	Natural gas	-0.83	-1.60		
Beierlin, Dunn & McConnor (1981)	Commercial	1967–77	Natural gas	-0.161	-1.06	-0.33	-2.19
Beierlin, Dunn & McConnor (1981)	Commercial	1967–77	Natural gas	-0.276	-1.865	0.035	0.237
Mount, Chapman & Tyrrell (1973)	Commercial	1946–70	Electric	-0.52	-1.47	0.30	0.85
McFadden & Puig (1975)	Commercial	1972	Electric		-0.54		0.80
Murray, Spann, Pulley & Beauvais (1978)	Commercial	1958–73	Electric	-0.07	-0.67	0.02	0.70
Chern & Just (1982)	Commercial	1955–74	Electric	-0.47	-1.32	0.25	0.70
DOE (1978)	Commercial	1960–75	Natural gas	-0.32	-1.06		
Nelson (1975)	Commercial-Residential	1971	Space heating	-0.3			
Uri (1975)	Commercial		Electric	-0.34	-0.85	0.79	1.98
FEA (1976)	Commercial		Natural gas	-0.38	large	0.73	large
			Distillate	-0.55	0.55	0.73	0.73

MODEL INPUT: Commercial sector renewable energy consumption projection

VARIABLE NAME: SolarRenewableContrib

MODEL COMPONENT: Service Demand

DEFINITION: Contribution of solar thermal energy consumed to meet commercial sector service demands by service *s*

CLASSIFICATION: Input from file KRENEW

DISCUSSION:

Solar water heating technologies are included in the Technology Choice submodule, allowing endogenous computation of solar consumption based on the selection of these technologies. A baseline projection for solar thermal energy consumption for space heating, developed by the National Renewable Energy Laboratory (NREL), is read into the CDM because projections from the NEMS Renewable Fuels Module are not currently available at the level of disaggregation required by the CDM. The renewable energy projections for active solar space heating are applied, interpolating to fill in the five-year forecast intervals provided in the white paper.

Commercial sector consumption of geothermal technologies is explicitly modeled by including geothermal or ground-source heat pumps in the technology characterization menu, allowing geothermal technologies to compete in the marketplace. Consumption of the renewable fuels, including biomass sources, such as wood- and municipal solid waste (MSW), as sources of cogeneration is also modeled explicitly, using data from the Form EIA-860, *Annual Electric Generator Report*.

SOURCES:

The Potential of Renewable Energy: An Interlaboratory White Paper, a report prepared for the Office of Policy, Planning and Analysis, U.S. Department of Energy, Golden, Colorado, March 1990.

U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*, database.

MODEL INPUT: Equipment efficiency

VARIABLE NAME: TechEff

MODEL COMPONENT: Technology Choice

DEFINITION: Efficiency, Coefficient of Performance, Seasonal Performance Factor, Efficacy (lighting), of equipment in providing service

CLASSIFICATION: Input from file KTEKX

DISCUSSION:

Equipment efficiencies for the services of space heating, space cooling, water heating, ventilation, cooking, lighting, and refrigeration are included in the Technology Characterization Menu of the NEMS CDM. These input data are composites of commercial sector equipment efficiencies of existing and prototypical commercial sector technologies provided in the sources cited below.

SOURCES:

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies – Reference Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates - Residential and Commercial Building Technologies – Advanced Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case* Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

Navigant Consulting, Inc., EIA - Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

U.S. Congress, House of Representatives. Energy Policy Act of 1992: Conference Report to Accompany H.R. 776, 102nd Cong., 2d sess. October 5, 1992.

MODEL INPUT: Consumer risk-adjusted time preference distribution data

VARIABLE NAME: TimePrefPrem

MODEL COMPONENT: Technology Choice

DEFINITION: The consumer risk-adjusted time preference interest rate premium is a percentage increment to the risk-free commercial sector interest rate. The module also requires the set of proportions of commercial consumers with each risk-adjusted time preference interest rate premium segment.

CLASSIFICATION: Input from file KPREM

DISCUSSION:

The preference distribution data are composites developed using a set of distributions of consumer payback period requirements from the literature and recent surveys that examine perceptions of energy efficiency and green building practices. The principal data sources for these inputs are cited below. These sources include Navigant (2014); Koomey (1990); DAC/ Leidos (formerly SAIC) (1992), which incorporates four electric utility studies; and an EIA market study. Three of the distributions were based on specific technologies, and two applied generally to all technologies. These data are not sufficient to identify statistically significant differences in commercial sector consumer payback requirements between classes of technologies. Furthermore, some of the utility sources represent *best guess* rules used to characterize potential demand-side management customers rather than data from a statistical survey. Therefore, because these limited data preclude the development of risk-adjusted time preferences as functions of technology characteristics, an average distribution across all technologies is applied.

We originally calculated the average consumer risk-adjusted time preference distribution as follows. Each source lists the proportions of commercial sector consumers with payback requirements by year, from 0 to 10 years. These payback requirements are first converted to implied internal rates of return for each year of the distribution for each source.[28] Then the risk-free interest rate (for the study, the 10-year Treasury note rate for the year corresponding to the payback study was used) is subtracted from

[28] The conversion to implied internal rates of return assumed mid-year payments and a 30-year amortization period.

each implied rate of return to yield a consumer risk-adjusted time preference premium distribution for each source.[29] Each distribution is discrete, consisting of 11 cells, corresponding to the 11 payback years. These distributions are subjected to a simple arithmetic average across studies to form a composite distribution.[30] Finally, the resulting average distribution is aggregated to yield a distribution of six risk-adjusted time preference segments. We have added a seventh risk-adjusted time preference segment to represent the risk-free interest rate, the rate at which the federal government is mandated to make purchase decisions. To model the EISA07 provision mandating energy-efficient lighting in federal buildings to the maximum extent possible, the results of the average distribution have been modified for this end use. Time preference premiums assumed for 2009 and later years were adjusted based on the results of the recent surveys on energy efficiency and green building practices cited below. Further discussion of these adjustments and lists of the distributions from each source as well as the resulting values assumed for input into NEMS are in Appendix E in the Risk-Adjusted Time Preference Premium Distribution data quality discussion.

The assumed distribution of consumer risk-adjusted time preference premiums is generally assumed to be constant over the projection period. However, the CDM allows variation in the distribution on an annual basis to accommodate targeted policies that may affect decision-making for specific time periods, such as Recovery Act spending, and for simulation of policy scenarios targeting consumers' implicit discount rates.

SOURCES:

Building Design+Construction, *Green Buildings + Climate Change*, Oak Brook IL, November 2008.

Decision Analysis Corporation of Virginia and Leidos (formerly Science Applications International Corporation), *Alternative Methodologies for NEMS Building Sector Model Development: Draft Report*, prepared for EIA under Contract No. DE-AC01-92EI21946, Task 92-009, Subtask 4, Vienna VA, August 1992, p. 14.

Institute of Real Estate Management (IREM) of the National Association of Realtors, "Building Performance that Pays: Insights from the First IREM Energy Efficiency Survey," 2017.

Johnson Controls, *2011 Energy Efficiency Indicator: IFMA Partner results*, October 2011.

Koomey, Jonathan G., *Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies*, Ph.D. Dissertation, University of California at Berkeley, 1990, p. 16.

Navigant Consulting, Inc., "The Leading Edge of New Energy Efficiency and Renewable Energy Technologies Coming to the Market," webinar, September 2014.

[29] The Treasury note rates were obtained from the Statistical Abstract and from personal communication with EIA's Macro and Financial Information staff.

[30] The proportions for the 11 cells were averaged directly. The consumer time preference premiums for each cell were averaged, weighting by the proportion of consumers. These rates differed slightly because of variations in the zero-risk interest rate between sources.

U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States 1990* (110th ed.), Washington, DC, 1990, p. 510.

MODEL INPUT: Equipment characteristics (see Definition below)

VARIABLE NAMES: TechCost, TechLife

MODEL COMPONENT: Technology Choice

DEFINITION: Installed unit capital cost, annual operating and maintenance cost, and equipment lifetime in years for specific technologies/models

CLASSIFICATION: Input from file KTEKX

DISCUSSION:

We combine capital and installation costs to form installed capital costs, based on available data. The Technology Choice algorithm does not require the separation of capital and installation costs, and currently it does not retain information describing absolute equipment capacity. Installed unit capital costs (installed capital cost per thousand British thermal units per hour of output capacity, or per 1,000 lumens in the case of lighting, or per 1,000 cubic feet per minute for ventilation systems) and the annual unit operating and maintenance costs vary by technology and vintage for the services of space heating, space cooling, water heating, ventilation, cooking, lighting, and refrigeration. They are developed from a variety of sources, referenced below.

SOURCES:

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case* Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case* Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, prepared for U.S. Energy Information Administration, August 2016.

U.S. Congress, House of Representatives, Energy Policy Act of 1992: Conference Report to Accompany H.R. 776, 102nd Cong., 2d sess. October 5, 1992.

MODEL INPUT: Equipment Availability

VARIABLE NAME: TechAvailability

MODEL COMPONENT: Technology Choice

DEFINITION: Availability of equipment technology and model by year

CLASSIFICATION: Input from file KTEKX

DISCUSSION:

The first year in which technologies become available corresponds to efficiency and cost data in the sources cited below for space heating, space cooling, water heating, and lighting technologies. In addition, the National Energy Policy Act of 1992 Title I, Subtitle C, Sections 122 and 124, provides commercial equipment efficiency standards applicable to units manufactured after January 1, 1994. The U.S. Department of Energy has continued to update applicable standards over time, and recent legislation has expanded the slate of equipment subject to equipment efficiency standards with standard levels announced and codified in the *Federal Register*. The companion document, *Assumptions to the Annual Energy Outlook 2018*, provides more information about the specific commercial equipment subject to standards. This information is combined with the previously cited sources and professional expectations to estimate the first-available and last-available year for each technology that is subject to the standards.

SOURCES:

National Archives and Records Administration, Office of the Federal Register, *Federal Register*, Volume 59 through Volume 74.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, prepared for U.S. Energy Information Administration, August 2016.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, prepared for U.S. Energy Information Administration, August 2016.

U.S. Congress, House of Representatives, *Energy Policy Act of 1992: Conference Report to Accompany H.R. 776*, 102nd Cong., 2d sess. October 5, 1992.

U.S. Department of Energy, Office of Research and Standards, *Draft Technical Support Document: Energy Efficiency Program for Commercial and Industrial Equipment: High-Intensity Discharge Lamps*, Washington, DC, August 2004.

MODEL INPUT: Distributed Generation Equipment Characteristics

VARIABLE NAMES: degrad, eleff, eqlife, txlife, dep, instcost, capcost, maintcst, avail, whrecovery, txcrpct, txcrmaxperkw, txcrmaxpersys (taxcreditmax), kW, lossfac, operhours, ifirstyr, ilastyr, ifueltype, equipname, intervalcst, iIntervalYrs, kwmin, kwmax, ScaleFac, RPS, rpsstartyear, rpsphaseoutyear

MODEL COMPONENT: CDistGen

DEFINITION:

Cost and performance of specific technologies (system capacity, cost per kilowatt, efficiencies, etc.).

Operating assumptions for specific technologies (hours of operation, conversion losses, and forced outage rates).

Tax credits, if any apply to a particular technology (tax credit policies may be included in the economic considerations).

The technology window of availability—technologies are assumed to be available for a fixed interval of time after which a new technology characterization becomes operable.

Economic assumptions (tax rate, tax lives, declining balance percentage for depreciation allowances).

CLASSIFICIATION: Input from file KGENTK

DISCUSSION:

degrad (technology, vintage)—degradation of conversion efficiency of technology. Currently applies to photovoltaics (PV) at a loss of 1% of total output per year. That is, after 20 years, a 5 kilowatt system would produce only 80% (1-20*1%) of its rated output, or 4 kW.

eleff (technology, vintage)—the electrical conversion efficiency of the technology and vintage.

eqlife (technology, vintage)—life of the equipment, specific to the equipment type as well as vintage.

txlife (technology, vintage)—tax life of building equipment (currently set to 5 years for PV, 39.5 years for all other distributed generation technologies).

dep (technology, vintage)—percentage to be used for depreciation calculation. A value of 100% signifies straight-line depreciation while a value of 150 or 200 results in accelerated declining balance depreciation. Non-PV generation technologies use straight-line depreciation in default operation, and PV is automatically set to 200% per current tax law.

whrecovery (technology, vintage)—waste heat recovery factor for technologies that burn fuel (that is, not photovoltaics). This waste heat can then be made available for water heating, which provides additional energy cost savings for distributed generation technologies.

instcost (technology, vintage)—installation cost in constant dollars per kilowatt.

capcost (technology, vintage)—capital cost of the investment in constant dollars per kilowatt.

maintcost (technology, vintage)—annual maintenance cost in constant dollars per kilowatt.

avail (technology, vintage)—percentage of time available (1 – forced outage rate – planned outage rate) applied to typical operating hours.

taxcreditmax (technology, vintage)—cap on the total dollar amount of a tax credit (if any).

txcrpct (technology, vintage)—tax credit percentage that applies to each technology's total installed cost (if any).The permanent business energy investment tax credit (ITC) for solar photovoltaics , fuel cells, microturbines, , wind turbines is discussed in the AEO annual assumptions report.

txcrmaxperkw (technology, vintage)—per-kilowatt cap on the dollar amount of a tax credit (if any).

txcrmaxpersys (technology, vintage)—per-system cap on the dollar amount of a tax credit (if any).

kW (technology, vintage)—kilowatts of typical system. Note capacity must remain constant across vintages for each technology.

operhours (technology)—typical operating hours.

lossfac (technology, vintage)—conversion losses (for systems that are rated *at the unit* rather than per available alternating current wattage) if appropriate.

ifirstyr (technology, vintage)—first year that a technology is available.

ilastyr (technology, vintage)—last year that a technology is available (Note: the input files are now structured with new vintages for each NEMS model year. Even so, the technology ranges are still operable and the use of *vintage* is maintained even though *year* would also be appropriate.).

ifueltype (technology)—fuel type pointer for generation technologies other than photovoltaics, currently this fuel type pointer is 2 for natural gas that is used by fuel cells.

equipname (census division, technology, vintage)—character string variable with equipment type name for report writer.

intervalcst (technology = 1, vintage)—interval maintenance cost for photovoltaic system direct current-to-alternating current (DC-to-AC) inverter replacement.

iIntervalYrs (technology = 1, vintage)—DC-to-AC inverter replacement interval in years for solar photovoltaic systems.

kwmin—varies by technology, smallest unit in terms of peak capacity allowed

kwmax—varies by technology, largest unit in terms of peak capacity allowed

ScaleFac—cost adjustment parameter for DG technology peak system capacity scale economies

RPS—renewable portfolio credit scalar (for example, triple RPS credit would be a user input value of 3.0)

rpsphaseoutyear—last year of renewable portfolio standard credits for cases where the credit is *sunsetted*

SOURCES:

System Capacities and Operating Hours are U.S. Energy Information Administration assumptions.

Solar Insolation - NREL communication to DOE.

Lawrence Berkeley National Laboratory, *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States*, Berkley, CA, September 2021.

Leidos, Inc., *Analyze Distributed Generation, Battery Storage, and Combined Heat and Power Technology Data and Develop Performance and Cost Estimates and Analytic Assumptions for the National Energy Modeling System: Final Report,* Washington, DC, April 2020.

National Renewable Energy Laboratory (NREL), *Annual Technology Baseline*, Golden, CO, 2021.

PV, wind accelerated depreciation - Internal Revenue Code, subtitle A, Chapter 1, Subchapter B, Part VI, Section 168 (1994) - accelerated cost recovery. CITE: 26USC168

MODEL INPUT: Distributed Generation Financial Inputs

VARIABLE NAMES: term, intrate, downpaypct, taxrate, inflation

MODEL COMPONENT: CDistGen

DEFINITION: Economic assumptions (loan rate and term, down payment percentage, tax rate, inflation rate for projecting nominal dollar values for the cash-flow model).

CLASSIFICIATION: Input from file KGENTK

DISCUSSION:

term—loan term currently set at 15 years

intrate—commercial mortgage rate from the kgentk input file, currently set to 8.5%.

downpaypct—down payment percentage assumed to apply to the distributed generation investment, currently 25% of the installed cost

taxrate—marginal combined federal and state income tax rate, currently assumed to be 40% for the typical commercial business inflation—inflation assumption for converting constant dollar fuel costs and fuel cost savings into current dollars for the cash-flow model to make the flows correspond to the nominal dollar loan payments. The current assumption is 3% annually.

SOURCES:

U.S. Energy Information Administration, estimated values and assumptions.

MODEL INPUT: Distributed Generation Program-Driven Penetrations

VARIABLE NAMES: exogpen, bldgshare

MODEL COMPONENT: CDistGen

DEFINITION: Exogenous, historical, and program-driven cumulative installed generation capacity by census division and technology. In projection years, these capacities are viewed as noneconomic penetrations and supplemental to any economic penetrations determined by the model. Technology-specific allocation shares for the exogenous penetrations for the commercial model building types are also required.

CLASSIFICIATION: Input from file KGENTK

DISCUSSION:

See definition.

SOURCES:

Exogenous penetrations: Developed from news releases—DOE and industry, the Solar Energy Industries Association, the Interstate Renewable Energy Council, the American Wind Energy Association, UPVG website, and estimated impacts from California's solar initiative and other state programs.

Building shares for exogenous penetrations by technology: Form EIA-860.

MODEL INPUT: Distributed Generation Building-Specific Characteristics and Niche Variables

VARIABLE NAMES: cbecsflspccatshare, cbecsavgsqft, elecavgkwh, waterhtgmmbtu, spacehtgmmbtu, ratescalar, ngratescalar, roofareatosqft, mps, solarinsolation, sqftshare

MODEL COMPONENT: CDistGen

DEFINITION: Average electricity usage, average annual water heating energy consumption, average annual space heating energy consumption.

CLASSIFICIATION: Input from data statements in subroutine CDistGen

DISCUSSION:

All of the variables in this group are developed from CBECS.

Size class and building type inputs—all of the following vary by census division, building type, and building size category:

> cbecsflspcatshare—share of floorspace area within a census division for a specific building type and size class combination.
>
> cbecsavgsqft—average floorspace area.
>
> elecavgkwh—average annual electricity usage in kilowatthours (kWh).
>
> spacehtgmmbtu—average annual space heating EUI; developed from ComEUI (see energy use intensity model input section above for ComEUI definitions) for space heating and average floorspace area for specific building type and size class combinations; units are million British thermal units (MMBtu) per year.
>
> waterhtgmmbtu—average annual space heating EUI; developed from ComEUI (see energy use intensity model input section above for ComEUI definitions) for space heating and average floorspace area for specific building type and size class combinations; units are MMBtu/year.

Niche inputs—all of the following vary by solar and electricity rate combined niches within each census division:

> ratescalar—niche variable for electricity prices relative to the census division average price within a niche.
>
> ngratescalar—niche variable for natural gas prices relative to the census division average price within a niche.
>
> roofareatosqft—average roof area available per unit of floorspace area.
>
> mps—average wind speed for distributed wind turbines in meters per second, developed from NREL wind resource map overlaid with CBECS niche areas.
>
> solarinsolation—solar insolation for photovoltaics in average daily kWh per square meter, developed from NREL insolation map overlaid with CBECS niche areas.
>
> sqftshare—niche variable representing the floorspace area share of the combined solar and electricity price level niches within each census division.

SOURCES:

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files; December 2022: :

- Average annual electricity consumption by building type for census division and size categories
- Average building floorspace area by building type for census division and size categories

- Floorspace shares by building type for census division and size categories
- Floorspace shares, relative electricity cost, relative gas cost, and roof area to floorspace area within census division by solar insolation and electricity price niche

Solar insolation levels by census division, solar insolation niche, and electricity price niche—National Renewable Energy Laboratory solar resource maps.

Average wind speed maps by census division, solar insolation niche, and electricity price niche—National Renewable Energy Laboratory, *Wind Energy Resource Atlas of the United States, 1987*, United States Wind Resource Map: Yearly Electricity Production Estimated per Square Meter of Rotor Swept Area for a Small Wind Turbine.

MODEL INPUT: Distributed Generation Penetration Function Parameters

VARIABLE NAMES: alpha, a, b, c, inx, inxfy, inxly

MODEL COMPONENT: CDistGen

DEFINITION: Technology-specific penetration function parameters, interconnection limitation parameters.

CLASSIFICIATION: Input from file KGENTK

DISCUSSION:

The values for the technology-specific penetration function parameter *alpha*, which denotes maximum possible penetration with a one-year simple payback, are found in each technology's characterization data in file KGENTK.txt. Parameter *c* determines what proportion of the maximum possible penetration is eventually achieved over time, while parameters *a* and *b* influence how quickly penetration approaches the maximum. Parameters *a*, *b*, and *c* are estimated by census division and technology based on nonlinear least squares regressions on historical data.

Interconnection potential *inx* is census division-specific based on population-weighted aggregation of state scores indicating the presence of rules, regulations, and policies that affect utility-grid interconnection of distributed generation. State scores range from zero (closed to interconnection) to one (open to interconnection) and are based on information from the DSIRE Database of State Incentives for Renewables & Efficiency and analyst judgment. The parameters *Inxfy* and *Inxly* define the interval over which interconnection limitations decrease to 0.

SOURCES:

State-level policy information—Database of State Incentives for Renewables & Efficiency (DSIRE), August 2024.

Appendix B. Mathematical Description

Introduction

This section provides the formulas and associated mathematical descriptions that represent the detailed solution algorithms arranged by sequential submodule as executed in the NEMS CDM. The exception to this order is that items pertaining to the Distributed Generation and Combined-Heat-and-Power (CHP) Submodule are found at the end of Appendix B. The different sections are given for the key equations relating to floorspace, service demand, technology choice, end-use fuel consumption, benchmarking, and distributed generation. Conventions, nomenclature, and symbols used in the equations found in this appendix are defined below.

In general, the following conventions for subscript usage are observed in this section. Additional subscripts are defined later in this appendix where necessary. Discrete values assumed by the subscripts, and categories of such values, are described in Table 1 and Table 2 of Chapter 2:

Subscript	Description of dimension represented by subscript
r	Census division
B	NEMS CDM building type
b'	NEMS MAM building type
s	End-use service
f	Fuel
d	Equipment decision type (values of 1 through 3 correspond, respectively, to the New, Replacement, and Retrofit decision types)
t	Technology class
v	Vintage or model of floorspace or equipment, depending on usage
ct	Sensor and control technology
P	Consumer risk-adjusted time preference premium segment
Y	Year designation (unless otherwise indicated, year ranges from CBECsyear +1 through the projection period, based on 1990 having an index value of 1 in the Fortran code. The equations below treat y as the calendar year.)
Y	Year designation internal to the 30-year cash-flow analysis used in the choice of distributed generation equipment
X	Building stock designation (a value of 1 corresponds to existing buildings, a value of 2 corresponds to new construction)

In addition, the following standard mathematical symbols are used in the formulae, primarily to indicate over which values of the subscripts the formula is evaluated:

Symbol	Meaning
$\forall$	for all
$\in$	belonging to the category of
$\notin$	not belonging to the category of

∍	such that
∃	there exists
∄	there doesn't exist
*	multiplication

Use is also made of several variables that represent *flags*, indicating conditions observed by the model during input of certain data. These flag variables and their definitions are:

$FuelbyTech_{t,f}$:= 1 if technology t uses fuel f, and is 0 otherwise;

$TechbyService_{s,t}$:= 1 if technology t provides service s, and is 0 otherwise.

Most formulas are evaluated only for the current year of the projection period. Subscripts appearing on the left side of the equal sign (=) without explicit restrictions indicate that the formula is evaluated for every combination of applicable values of those subscripts. The variables over which summations are performed are indicated but often without restriction. In those cases, as with the subscripts, they assume all applicable values. Applicable values are generally all major and minor fuels for the fuel subscript *f*, all major services for the end-use subscript *s*, and all possible values for the remaining subscripts. In any event, fuels and services involved in calculations where technologies are explicitly referenced are always restricted to the major categories.

The equations follow the logic of the Fortran source code very closely to facilitate an understanding of the code and its structure. In several instances, a variable name will appear on both sides of an equal sign. The = sign in the following equation sections denotes assignment statements. An assignment statement is a computer programming device that allows a previously calculated variable to be updated (for example, multiplied by a factor) and re-stored under the same variable name. The equations and assignment statements are discussed in the text of Chapter 4. The variables appearing in the equations are cross-referenced and fully defined in Appendix A, Table A-1.

Floorspace equations

Logistic Building Survival Function:

$$CMSurvRate\,(b, y - y_0) = \frac{1}{1+\left(\frac{y-y_0}{CMAvgAge\,(b)}\right)^{CMGamma(b)}}, \qquad \text{B-1}$$

where y_0 ≡ year of construction.

Backcast CBECSyear existing floorspace to new construction in original year of construction:

$$CMNewFloorspace_{r,b,y'} = \frac{CBECSFlrSpc_{r,b,v}}{CMSurvRate(b, CBECSyear - y')}, \qquad \text{B-2}$$

where y' ≡ original year of construction = $CMVintage_{r,b,v}$ and v ranges over each of the 10 floorspace vintage ranges and represents the median year of construction within the intervals of:

- Before 1920

- 1920–1945
- 1946–1959
- 1960–1969
- 1970–1979
- 1980–1989
- 1990–1999
- 2000–2007
- 2008–2012
- 2013–2018

In this case, y' ranges from 1825 through 2012.

Previously constructed floorspace surviving into the current year:

$$SurvFloorTotal_{r,b,y} = \sum_{y'=CMOldestBldgVint}^{y-1} \left[CMNewFloorSpace_{r,b,y'} * CMSurvRate_{b,y-y'}\right]. \quad \text{B-3}$$

New commercial floorspace estimated using Macroeconomic Activity Module growth rates:

$$CMNewFloorSpace_{r,b,y} = \mathrm{CMTotalFlspc}_{r,b,CBECSyear} * MC\_COMMFLSP_{r,b,y} - SurvFloorTotal_{r,b,y}. \quad \text{B-4}$$

Revised projection of new commercial floorspace construction and total floorspace:

$$CMNewFloorSpace_{r,b,y} = MAX\left(CMNewFloorSpace_{r,b,y}, \mathbf{0}\right). \quad \text{B-5}$$

$$CMTotalFlspc_{r,b,y} = SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}. \quad \text{B-6}$$

Service demand equations

Total Energy Use Intensities:

$$ComEUI_{r,b,s,F} = \sum_{f \in \{MajorFuels\}} ComEUI_{r,b,s,f}, \quad \text{B-7}$$

where F ≡ CMnumMajFl + 1, is used to store the total across all major fuels (electricity, natural gas, and distillate fuel oil).

Split Office Equipment EUI into PC and non-PC:

If BaseYrPCShrofOffEqEUI ≥ 0, then B-8

$$ComEUI_{r,b,s=PCOffEq,f} = ComEUI_{r,b,s=PCOffEq,f} * (1 - BaseYrPCShrofOffEqEUI),$$

$$\boldsymbol{ComEUI_{r,b,s=NonPCOffEq,f} = ComEUI_{r,b,s=PCOffEq,f} * BaseYrPCShrofOffEqEUI.}$$

Otherwise, these quantities remain unchanged.

Total consumption by end use in CBECSyear:

$$\boldsymbol{CforStotal_{[r,s,CBECSyear]} = \sum_b \left[ComEUI_{r,b,s,F} * CMTotalFlspc_{r,b,CBECSyear}\right].} \qquad \text{B-9}$$

End-use fuel consumption in CBECSyear in buildings to which particular equipment is restricted:

$$\boldsymbol{CforSrestrict_{t,v,r,s} = \sum_b \left[ComEUI_{r,b,s,F} \cdot CMTotalFlspc_{r,b,CBECSyear} * \left(1 - EquipRestriction_{b,r,t,v}\right)\right],} \qquad \text{B-10}$$

if the vintage *v* is available in the CBECS base year.

Revise initial equipment market shares to reflect building restrictions:

$$\boldsymbol{TechShareofServiceBASE_{r,b,s,t,v} = MarkShar_{rb,s,t,v} * \frac{CforStotal}{CforSrestrict},} \qquad \text{B-11}$$

if the vintage *v* is not restricted in building type *b* and is available in the CBECS base year.

$$\boldsymbol{TechShareofService_{r,b,s,t,v} = \frac{TechShareofServiceBASE_{r,b,s,t,v}}{\sum_{b'} \sum_{t',v'} TechShareofServiceBASE_{r,b',s,t',v'}},} \qquad \text{B-12}$$

if the vintages *v* and ***v'*** are available in the CBECS base year.

Here, *b'* is used as an alternative NEMS CDM building type index rather than as a NEMS MAM building type index to represent an expression that depends both on a particular building type and a summation over all building types.

Average equipment efficiency in the CBECS base year by fuel, end use, building type, and census division:

$$\boldsymbol{AverageEfficiencyBASE_{r,b,s,f} = \frac{\sum_{\forall\, t,v \ni FuelbyTech(t,f)-1} TechShareofServiceBASE_{r,b,s,t,v}}{\sum_{\forall\, t,v \ni FuelbyTech(t,f)-1} \left(\frac{TechShareofServiceBASE_{r,b,s,t,v}}{TechEff_{r,s,t,v}}\right)}.} \qquad \text{B-13}$$

Apply fuel-specific factor to bring CBECSyear equipment market shares and EUIs into agreement:

$$\boldsymbol{KScale_{r,b,s,f} = \frac{\frac{ComEUI_{r,b,s,f}}{ComEUI_{r,b,s,F}} * \left[\frac{AverageEfficiencyBASE_{r,b,s,f}}{\sum_{t,v \ni FuelbyTech(t,f)-1} TechShareofServiceBASE_{r,b,s,t,v}}\right]}{\sum_{f' \in \{MajFl\}} \left[\frac{ComEUI_{r,b,s,f'}}{ComEUI_{r,b,s,F}} * AverageEfficiencyBASE_{r,b,s,f'}\right]},} \qquad \text{B-14}$$

$$TechShareofServiceBASE_{r,b,s,t,v} = TechShareofServiceBASE_{r,b,s,t,v} * KScale_{f},$$ B-15

where *f* is the major fuel corresponding to technology *t* and vintage *v*.

Service demand intensities (SDIs) prevailing in the CBECS base year:

For major services:

$$ServDmdIntenBASE_{s,b,r} = \frac{ComEUI_{r,b,s,F}}{\sum_{\forall\, t,v \ni TechEff_{r,s,t,v} \neq 0}\left(\frac{TechShareofServiceBASE_{r,b,s,t,v}}{TechEff_{r,s,t,v}}\right)},$$ B-16

$s \in \{Major\ Services\}$; $F =$ total across fuels $= CMnumMajFl + 1.$

For minor services:

$$ServDmdIntenBASE_{s,b,r} = ComEUI_{r,b,s,f},$$ B-17

$s \in \{Minor\ Services\}$; $F =$ total across fuels $= CMnumMajFl + 1.$

Basic projection of service demands in floorspace surviving into current year:

$$ServDmdExBldg_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \cdot 10^{-3} \cdot SurvFloorTotal_{r,b,y},$$ B-18

$s \in \{Major\ Services\}.$

The 10^{-3} in this equation converts units from billion Btu to trillion Btu.

Interpolate the current year shell heating and cooling efficiency of surviving base-year floorspace:

$$ExistShBaseStockHt_{s,b,r,y} = \left(ExistImprovHt_{b,r})^{\frac{1}{(Projection\ Horizon - CBECSyear)}}\right)^{(y-CBECSyear)},$$ B-19

$s \in \{SpHeat\}.$

$$ExistShBaseStockCl_{s,b,r,y} = \left(ExistImprovCl_{b,r})^{\frac{1}{(Projection\ Horizon - CBECSyear)}}\right)^{(y-CBECSyear)},$$

$s \in \{SpCool\}.$ B-20

Compute the shell heating and cooling factors of surviving floorspace:

$$ShellHeatFactor_{b,r,l,y} = \frac{(ExistShBaseStockHt_{b,r,y}\,(SurvFloorTotal_{r,b,y} - TotNewFS) + NewShlAvgHt)}{SurvFloorTotal_{r,b,y}},$$

$s \in \{SpHeat\}.$ B-21

$$ShellCoolFactor_{b,r,l,y} = \frac{(ExistShBaseStockCl_{b,r,y}\,(SurvFloorTotal_{r,b,y} - TotNewFS) + NewShlAvgCl)}{SurvFloorTotal_{r,b,y}},$$
$s \in \{SpCool\}$. B-22

Adjust for the effect of improving shell efficiencies on service demands in surviving floorspace:

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} * ShellHeatFactor_{b,r,1},$$
$s \in \{SpHeat\}$. B-23

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} * ShellCoolFactor_{b,r,1},$$
$s \in \{SpCool\}$. B-24

Basic projection of service demands in new floorspace construction:

$$NewServDmd_{s,b,r,y} = ServDmdIntenBASE_{s,b,r,y} * 10^{-3} * CMNewFloorspace_{r,b,y},$$
$s \in \{Major\ Services\}$. B-25

The 10^{-3} converts units from billion Btu to trillion Btu.

Calculate the current year improvement to new shell cooling efficiency:

$$NewShlAvgCl_y = NewShlAvgCl_y + CMNewFloorSpace_{b,r,y} * ShellCoolFactor_{b,r,2,y},$$
$s \in \{SpCool\}$. B-26

Calculate the current year improvement to new shell heating efficiency:

$$NewShlAvgHt_y = NewShlAvgHt_y + CMNewFloorSpace_{b,r,y} * ShellHeatFactor_{b,r,2,y},$$
$s \in \{SpHeat\}$. B-27

Adjust for the effect of improving shell efficiencies on service demands in new floorspace:

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} * ShellHeatFactor_{b,r,2},$$
$s \in \{SpHeat\}$. B-28

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} * ShellCoolFactor_{b,r,2},$$
$s \in \{SpCool\}$. B-29

Calculation of data center share of floorspace for each NEMS building type:

$$\boldsymbol{DatCtrShare = 0.000002 * (y - CMFirstYr)^3 - 0.000002 * (y - CMFirstYr)^2 + 0.0173 * (y - CMFirstYr),}$$
$$\boldsymbol{if\ y > ksteoyr.}$$
$$\boldsymbol{DatCtrShare = 0, otherwise.}$$
$$\boldsymbol{CMFirstYr = CBECSyear + 1.}$$
B-30

Equation B-30 expresses the assumed share of floorspace attributed to on-premise data centers to account for the additional services required by these facilities.[31]

Effect of data center requirements on demands for certain services, new and existing buildings:

$$\boldsymbol{ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} * (1 - DatCtrShare) + ServDmdExBldg_{s,b,r,y} * DatCtrShare * dcf_s,}$$
B-31

$$\boldsymbol{NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} * (1 - DatCtrShare) + NewServDmd_{s,b,r,y} * DatCtrShare * dcf_s,}$$
$$\boldsymbol{s \in \{SpCool\},}$$
$$\boldsymbol{b \in \{Large\ Office\},}$$
B-32

where dcf_s is the ratio of the service demand intensity in on-premise data centers to the service demand intensity of buildings without data centers for service *s*.

Effect of serviced floorspace proportion difference between surviving and new construction:

$$\boldsymbol{NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} * \frac{ServicedFlrspcProp_{b,s,new}}{ServicedFlrspcProp_{b,s,existing}},}$$
$$\boldsymbol{s \leq CMnumVarSDI.}$$
B-33

Minor service demand projection with CBECSyear average efficiency indexed to one:

$$\boldsymbol{ServDmdExBldg_{s,b,r,y} = ServDmdIntenBASE_{s,b,r,y} * 10^{-3} * SurvFloorTotal_{r,b,y},}$$
$$\boldsymbol{s \in \{MinorServices\}.}$$
B-34

$$\boldsymbol{NewServDmd_{s,b,r,y} = ServDmdIntenBASE_{s,b,r,y} * 10^{-3} * CMNewFloorspace_{r,b,y},}$$
$$\boldsymbol{s \in \{MinorServices\}.}$$
B-35

[31] Data center floorspace estimates are based on Mitchell-Jackson, Jennifer, "Energy Needs in an Internet Economy: A Closer Look at Data Centers," Lawrence Berkeley National Laboratory, July 2001 and Stein, Jay, "More Efficient Technology Will Ease the Way for Future Data Centers," 2002 ACEEE Summer Study on Energy Efficiency in Buildings Proceedings, August 2002.

The 10^{-3} in these equations converts units from billion Btu to trillion Btu.

Effect of continuing market penetration on demands for certain electricity-based services, new and existing buildings:

$$\begin{aligned} &\boldsymbol{ServDmdExBldg_{s,b,r,y}} \\ &\quad = \boldsymbol{ServDmdExBlg_{s,b,r,y}} * \boldsymbol{ServicesIndex_y} * (\boldsymbol{1} - \boldsymbol{xplicitmiscshr_b}) \\ &\quad * \sum_{f=1}^{3} \boldsymbol{FuelShareofServiceBase_{r,b,s,f}}, \\ &\boldsymbol{s} \in \{\boldsymbol{Other}, \boldsymbol{Non-specific}\}. \end{aligned} \quad \text{B-36}$$

$$\begin{aligned} &\boldsymbol{ServDmdExBldg_{s,b,r,y}} = \boldsymbol{ServDmdExBlg_{s,b,r,y}} * \boldsymbol{OfficePCPenetration_y}, \\ &\boldsymbol{s} \in \{\boldsymbol{Office\ Equipment}, \boldsymbol{PC}\}. \end{aligned} \quad \text{B-37}$$

$$\begin{aligned} &\boldsymbol{ServDmdExBldg_{s,b,r,y}} = \boldsymbol{ServDmdExBlg_{s,b,r,y}} * \boldsymbol{OfficeNonPCPenetration_y}, \\ &\boldsymbol{s} \in \{\boldsymbol{Office\ Equipment}, \boldsymbol{NonPC}\}. \end{aligned} \quad \text{B-38}$$

$$\begin{aligned} &\boldsymbol{NewServDmd_{s,b,r,y}} \\ &\quad = \boldsymbol{NewServDmd_{s,b,r,y}} * \boldsymbol{MarketPenetrationMels_{s,y}} * (\boldsymbol{1} - \boldsymbol{xplicitmiscshr_b}) \\ &\quad * \sum_{f=1}^{3} \boldsymbol{FuelShareofServiceBase_{r,b,s,f}}, \\ &\boldsymbol{s} \in \{\boldsymbol{Other}, \boldsymbol{Non-specific}\}. \end{aligned} \quad \text{B-39}$$

$$\begin{aligned} &\boldsymbol{NewServDmd_{s,b,r,y}} = \boldsymbol{NewServDmd_{s,b,r,y}} * \boldsymbol{OfficePCPenetration_y}, \\ &\boldsymbol{s} \in \{\boldsymbol{OfficeEquipment}, \boldsymbol{PC}\}. \end{aligned} \quad \text{B-40}$$

$$\begin{aligned} &\boldsymbol{NewServDmd_{s,b,r,y}} = \boldsymbol{NewServDmd_{s,b,r,y}} * \boldsymbol{OfficeNonPCPenetration_y}, \\ &\boldsymbol{s} \in \{\boldsymbol{Office\ Equipment}, \boldsymbol{NonPC}\}. \end{aligned} \quad \text{B-41}$$

Service demand projections for specified categories within MELs, including continuing market penetration, are based on electricity consumption estimates and projected national-level trends from studies completed by TIAX LLC, Navigant Consulting, and Leidos. Polynomial equations are fitted to the trends to describe the projected energy use intensity (EUI) for each of the specified categories. The resulting EUI is multiplied by the floorspace appropriate to the specified category to obtain projected electricity consumption. In this case, service demand is assumed to be the same as electricity consumption because any efficiency improvements and additional market penetration are included in the projected trends.[32]

[32] The exceptions to this treatment are municipal water and telecom services. Electricity consumption for these services is included in non-building energy consumption with specific equations described in the Benchmarking Equations section.

Calculation of floorspace of building types with demand for the type of services in a specific category of electricity-based services within MELs:

$$BrewerFlrBase = \sum_{b\in\{4,7,8\}}\left(CMSurvFloorTot_{b,y} + CMNewFlrSpace_{b,y}\right) * 1000. \qquad \text{B-42}$$

BrewerFlrBase is the sum of floorspace in food service, large office, and small office buildings, or building types 4, 7, and 8 per Table 1, respectively, with demand for coffee brewers. A similar method is used to calculate LaundryFlrBase, MedFlrBase, ElevatorFlrBase, EscalatorFlrBase, LabFlrBase, KitchenFlrBase, OfficeFlrBase, and TotFlrNoWhse based on the MELs specific to those building types as outlined in Table A-1. *BrewerFlrBase* pertains to the specific year for which it is calculated.

U.S. service demand projection for specific categories of electricity-based services within MELs:

$$USMiscElQ_{mc,y} = \left(MarketPenetrationMels_{mc,y}\right) * MelsELQ_{mc} * 10^{-3} * TotMiscFloorspace_{mc,y},$$
$$mc \in \{Specific\ miscellaneous\ use\ categories\ within\ Other\}. \qquad \text{B-43}$$

The 10^{-3} in this equation converts units from billion Btu to trillion Btu. Coefficient values associated with each electric MEL are provided in Appendix A.

Service demand for specific categories of electricity-based MELs services by census division and building type:

$$MiscElQ_{mc,r,b,y} = USMiscElQ_{mc,y} * \frac{CMTotalFlspc_{r,b,y}}{TotMiscFloorspace_{mc,y}},\ b \in mc.$$
$$MiscElQ_{mc,r,b,y} = 0,\ otherwise. \qquad \text{B-44}$$

$$TotExplicitMiscElQ_{r,b,y} = \sum_{mc} MiscElQ_{mc,r,b,y},$$
$$mc \in \{Specific\ miscellaneous\ use\ catergories\ within\ Other\}, \qquad \text{B-45}$$

where $CMTotalFlspc_{r,b,y}$ is the sum of $SurvFloorTotal_{r,b,y}$ and $CMNewFloorspace_{r,b,y}$.

Add service demand for specific categories to demand for MELs:

$$ServDmdExBldg_{10,b,r,y} = ServDmdExBldg_{10,b,r,y} + \left(TotExplicitMiscElQ_{r,b,y} * \frac{SurvFloorTotal_{r,b,y}}{CMTotalFlspc_{r,b,y}}\right), \qquad \text{B-46}$$

$$\boldsymbol{NewServDmd_{10,b,r,y} = NewServDmd_{10,b,r,y} + \left(TotExplicitMiscElQ_{r,b,y} * \frac{CMNewFloorspace_{r,b,y}}{CMTotalFlspc_{r,b,y}}\right)}, \quad \text{B-47}$$

where $CMTotalFlspc_{r,b,y}$ is the sum of $SurvFloorTotal_{r,b,y}$ and $CMNewFloorspace_{r,b,y}$.

Reduce demands by amounts satisfied using solar energy directly:

$$\boldsymbol{ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - \left(\frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} * \frac{SurvFloorTotal_{r,b,y}}{CMTotalFlspc_{r,b,y}}\right)},$$
$$\boldsymbol{s \in \{Solar\ Services\}}. \quad \text{B-48}$$

$$\boldsymbol{NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} + \left(\frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} * \frac{CMNewFloorspace_{r,b,y}}{CMTotalFlspc_{r,b,y}}\right)},$$
$$\boldsymbol{s \in \{Solar\ Services\}}, \quad \text{B-49}$$

where $CMTotalFlspc_{r,b,y}$ is the sum of $SurvfloorTotal_{r,b,y}$ and $CMNewFloorspace_{r,b,y}$. Solar services include heating, cooling, water heating, ventilation, lighting, and cooking.

Amount of service demand requiring replacement equipment as a result of equipment failure:

$$\boldsymbol{RetireServDmd_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} * \sum_{t \in T_s} \sum_{v} \left(\frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}}\right)},$$

where the sum is taken over all technologies *t* and vintages *v* pertaining to service *s.* B-50

$$\boldsymbol{ServDmdSurv_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - RetireServDmd_{s,b,r,y}},$$
$$\boldsymbol{y > CMFirstYr}. \quad \text{B-51}$$

Reduce service demand due to adoption of sensor and control technologies for major end-use services:

$$\boldsymbol{ServDmdExBldg_{s,b,r,y} = \frac{ServDmdExBldg_{s,b,r,y} * (1 - CT\_flag_{ct,s}) * pctSCSavings_{ct} * MarketPenetrationSC_{ct,b,y}}{(1 - CT\_flag_{ct,s}) * pctSCSavings_{ct} * MarketPenetrationSC_{ct,b,\Delta y}}},$$
$$\boldsymbol{ct \leq CMnumCt}. \quad \text{B-52}$$

where Δy is the number of years between the commercial base year, currently 2018, and the start of the historical period.

$$NewServDmd_{s,b,r,y} = \frac{NewServDmd_{s,b,r,y} * (1 - CT\_flag_{ct,s}) * pctSCSavings_{ct} * MarketPenetrationSC_{ct,b,y}}{(1 - CT\_flag_{ct,s}) * pctSCSavings_{ct} * MarketPenetrationSC_{ct,b,\Delta y}},$$

$ct \le CMnumCt.$

B-53

where Δy is the number of years between the commercial base year, currently 2018, and the start of the historical period.

Technology choice equations

Proportion of service demand affected by failed equipment:

$$ReplacementProportion_{r,b,s,t} = \sum_v \left(\frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}}\right),$$

for all technologies *t* pertaining to service *s*. The right-hand side sum is taken over all vintages *v* of technology *t*. B-54

Equipment share of service demand not requiring equipment replacement:

$$SurvivingShareofService_{[r],[b],[s],t,v} = PrevYrTechShareofService_{r,b,s,t,v} * \frac{\left(1 - \frac{1}{TechLife_{t,v}}\right)}{1 - ReplacementProportion_{r,b,s}},$$

for all technologies *t* and vintages *v* pertaining to service *s.* B-55

Failed equipment shares of service demand requiring equipment replacement:

$$SurvivingFuelShareofService_{r,b,s,f} = \sum_t SurvivingShareofService_{[r],[b],[s],t,v} * FuelbyTech_{t,f},$$

for all technologies ***t*** and vintages ***v*** pertaining to service ***s***. B-56

Fuel shares of service demand not requiring equipment replacement:

$$ReplacementShareofService_{r,b,s,t,v} = \frac{PrevYrShareofService_{r,b,s,t,v}\left[\frac{1}{TechLife_{t,v}}\right]}{ReplacementProportion_{r,b,s}},$$ B-57

for all technologies *t* and vintages *v* pertaining to service *s*.

Fuel shares of service demand requiring equipment replacement:

$$ReplacementFuelShareofService_{r,b,s,f,t} = \sum_v \left(ShareofService_{r,b,s,t,v}\ FuelbyTech_{t,f}\right),$$

for all technologies ***t*** and vintages ***v*** pertaining to service ***s***. B-58

Incremental cost of heat pump to provide heating over cost of standard cooling equipment:

$$\boldsymbol{TechCost_{r,CoolingTechIndenHP,t,v,l} = TechCost_{r,t,v,l} - TechCost_{r,CoolingTechIndenHP,v,l},}$$
$$\boldsymbol{t, v \ni \{Heat\ pumps\ for\ space\ heating\}.} \quad \text{B-59}$$

This one-time adjustment is performed following the input of *TechCost* from the KTEKX file. *CoolingTechIndexHP* represents the technology class of the standard cooling equipment.

Cost trend function when flag CostTrendSwitch is set to one:

For infant technologies:

$$\boldsymbol{KEqCost\,(t, v, y, CAP) = \frac{TechCost_{t,v,1} * \delta}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1 - \delta) * TechCost_{t,v,1}.}$$

For adolescent technologies:

$$\boldsymbol{KEqCost\,(t, v, y, CAP) = \frac{TechCost_{t,v,1} * 2\,\delta}{1 + \left(\frac{y - y_1}{y_0 - y_1}\right)^{\gamma}} + (1 - \delta) * TechCost_{t,v,1}.}$$

For mature technologies:

$$\boldsymbol{KEqCost\,(t, v, y, CAP) = TechCost_{t,v,l},} \quad \text{B-60}$$

where

γ =shape parameter corresponding to the rate of price decline;

$\delta =$ total anticipated percentage decline in real cost from the initial value;

$y_0 =$ year dictating the curve's inflection point;

$y_1 =$ effective year of introduction for the given technology; and

CAP = capital cost.

$TechCost_{t,v,1}$ is used if *CostTrendSwitch* is set to zero.

Calculate the shell efficiency factor for space heating and cooling equipment directly from the shell heating and cooling factors calculated in the Service Demand Submodule:

$$\boldsymbol{ShellEffFactor_{b,r,x} = ShellHeatFactor_{b,r,x},}$$
$$\boldsymbol{s \in \{SpHeat\}.} \quad \text{B-61}$$

$$\boldsymbol{ShellEffFactor_{b,r,x} = ShellCoolFactor_{b,r,x},}$$
$$\boldsymbol{s \in \{SpCool\},} \quad \text{B-62}$$

where the subscript *x* is 1 for existing buildings and 2 for new construction.

Effective hurdle (implicit discount) rate:

$$EffectHurdle = \frac{MC\_RMGBLUSREAL_y}{100} + TimePrefPrem_{s,p,y}. \qquad \text{B-63}$$

If $EffectHurdle \leq 0.15$ **or** $PriceDelta_{f,[r],[y],[s]} \leq 1$**,**

$$EffectHurdleAdj = EffectHurdle.$$

Otherwise,

$$EffectHurdleAdj = 0.15 + (EffectHurdle - 0.15) * \left(PriceDelta_{f,[r],[y],[s]}\right)^{HurdleElas_{r,s,f}},$$

where $PriceDelta_{f,[r],[y],[s]}$ is the ratio of price of fuel *f* in census division *r* during year *y* for end-use service *s* (the subscript *s* is only applicable for electricity prices) in the current year to the price in the CBECS base year. Brackets around *r, y,* and *s* denote subscripts that are implicit in the code. The variable *EffectHurdle* pertains to the specific service, decision type, and year for which it is calculated. *EffectHurdleAdj* pertains to the specific service, year, fuel, and region for which it is calculated.

Annualized cost of new equipment for stage 1 decision of least-cost behavior segment:

$$\begin{aligned} AnnualCostTech_{p,t,v,d} &= KEqCost\,(t,v,y,\text{CAP}) * \frac{EffectHurdle}{1-(1+EffectHurdle)^{-TechLife_{t,v}}} + TechCost_{t,v,2} \\ &* CapacityFactor_{r,b,s} + ShellEffFactor_x * \frac{ConvFactor}{TechEff_{r,s,t,v}} \\ &* CapacityFactor_{r,b,s} * FuelCost_{f_t,r,y,s}, \end{aligned}$$

where

$\text{ConvFactor} = 8.76$ **for all services except lighting**;

$\text{ConvFactor} = 0.03345^{-1}/\text{TechCRI}(r,s,t,v)$ **for** $s =$ **lighting**; **and**

$\text{f}_\text{t} =$ **fuel used by** t**.** B-64

AnnualCostTech pertains to the specific building type *b* and region *r* for which it is calculated.

Annualized cost of new equipment for same-fuel and same-technology behavior segments and stage 2 decision of least-cost behavior segment:

$$\begin{aligned} AnnualCostTechAdj_{p,t,v,d} &= KEqCost\,(t,v,y,\text{CAP}) * \frac{EffectHurdleAdj}{1-(1+EffectHurdleAdj)^{-TechLife_{t,v}}} \\ &+ TechCost_{t,v,2} * CapacityFactor_{r,b,s} + ShellEffFactor_x * \frac{ConvFactor}{TechEff_{r,s,t,v}} \\ &* CapacityFactor_{r,b,s} * FuelCost_{f_t,r,y,s}, \end{aligned} \qquad \text{B-65}$$

where
$\mathbf{ConvFactor = 8.76\ for\ all\ services\ except\ lighting}$;
$\mathbf{ConvFactor = \ 0.03345^{-1}/TechCRI(\mathit{r,s,t,v})\ for\ \mathit{s} = lighting}$; **and**
$\mathbf{f_t = fuel\ used\ by\ \mathit{t}.}$

The third subscript of *TechCost* is 1 for annual capital cost per unit of service demand and is 2 for annual operating and maintenance costs (excluding fuel costs). The variable *EffectHurdle* or *EffectHurdleAdj* is the effective hurdle or implicit discount rate for the current fuel, census division, service, and year, as calculated in equation B-63. *EffectHurdle* has a 3% floor per FEMP 10 CFR § 436.14. The variable *ShellEffFactor* is involved in the calculation only for space heating and space cooling and is set to *ShellHeatFactor* or *ShellCoolFactor* as appropriate. Because only the relative costs of choices are important within each building, to simplify the calculation actually evaluated by the model, the equation above is divided by *CapacityFactor*, which has the same value for all equipment providing a given service in each building type and census division. $ExpectPrice_{f_t,r,y,s}$ is the price of fuel *f* in census division *r* during year *y* for end-use service *s* (the subscript *s* is only applicable for electricity prices) for the default mode of myopic foresight and the expression in Equation B-64 when optional price expectations modeling is used. *ConvFactor* annualizes the fuel cost and, in the case of lighting, also converts fuel costs from dollars per MMBtu to dollars per kilowatt-year (necessary because lighting efficiency is in lumens per watt). Equations B-61 and B-62 also include an adjustment for *TechCRI* (the lighting color rendering index), which reduces the *effective efficiency* of low-CRI lighting technologies and renders them less attractive relative to higher-CRI options. *AnnualCostTechAdj* pertains to the specific building type and region for which it is calculated.

Expression for FuelCost when optional price expectations are used:

$$\boldsymbol{ExpectPrice_{f_t,r,t,v,y} \equiv \frac{1}{TechLife_{t,v}} * \sum_{y'=y}^{y+TechLife_{t,v}-1} Xprice_{f_t,r,y'}}$$

where
$\boldsymbol{f_t \equiv fuel\ used\ by\ t.}$ B-66

Least-cost behavior rule stage 1—identify least-cost equipment for fuel choice:

$\mathbf{Find}\ \boldsymbol{t, v}\ \mathbf{such\ that}\ \boldsymbol{AnnualCostTech_{p,t,v,d} \leq AnnualCostTech_{p,t',v',d} \forall\ t', v'}$;
$\mathbf{then}\ \boldsymbol{LCTNR\_AF\ l_{p,1,d} = t\ and\ LCTNR\_AF\ l_{p,2,d} = v,}$ B-67

where $LCTNR\_AF1_{p,1,d}$ represents the stage 1 technology class with the least annualized cost and $LCTNR\_AF1_{p,2,d}$ represents the stage 1 technology model with the least annualized cost for consumers in consumer risk-adjusted time preference segment *p* and decision type *d*.

Least-cost behavior rule stage 2—identify least-cost equipment using the same fuel as selected in stage 1:

$$\textbf{Find } t, v \textbf{ such that } AnnualCostTechAdj_{p,t,v,d} \leq AnnualCostTechAdj_{p,t',v',d}$$
$$\textbf{for all } t' \textbf{ and } v' \textbf{ such that } t \textbf{ and } t' \textbf{ correspond to the same fuel as the stage 1 technology class;}$$
$$\textbf{then } LCTNR\_AF_{p,1,d} = t \textit{ and } LCTNR\_AF_{p,2,d} = v, \quad \text{B-68}$$

where $LCTNRAF_{p,1,d}$ represents the technology class with the least annualized cost and $LCTNRAF_{p,2,d}$ represents the technology model with the least annualized cost for consumers in consumer risk-adjusted time preference segment *p* and decision type *d*.

Same-fuel behavior rule—identify least-cost equipment using the same fuel as the existing stock:

$$\textbf{Find } t, v \textbf{ such that } AnnualCostTechAdj_{p,t,v,d} \leq AnnualCostTechAdj_{p,t',v',d} \forall\, t', v',$$
$$\textbf{for all } t \textbf{ and } t' \textbf{ such that the corresponding fuel is } f.$$
$$\textbf{If such a } t \textbf{ and } v \textbf{ exist, then } LCTNR\_SF_{p,f,1,d} = t \textit{ and } LCTNR\_SF_{p,f,2,d} = v.$$
$$\textbf{If there is no such } t, \textbf{ then } LCTNR\_SF_{p,f,1,d} = LCTNR\_SF_{p,f,2,d} = 0, \quad \text{B-69}$$

where $LCTNR\_SF_{p,f,1,d}$ represents the technology class with the least annualized cost and $LCTNR\_SF_{p,f,2,d}$ represents the technology model with the least annualized cost for consumers in consumer risk-adjusted time preference segment *p* and decision type *d*.

Same-technology behavior rule—identify least-cost model in current technology class:

$$\textbf{Find } v \textbf{ such that } AnnualCostTech_{p,t,v} \leq AnnualCostTech_{p,t,v'} \forall\, v',$$
$$\textbf{then } LCVNR\_ST_{p,t,d} = v, \quad \text{B-70}$$

where $LCVNR\_ST_{p,t,d}$ represents the technology model with the least annualized cost for consumers in consumer risk-adjusted time preference segment *p* and decision type *d*.

Market shares of equipment within least-cost behavior segment of new decision type:

$$LCMSN_{t,v} = \sum_p TimePrefProp_{s,p,y},$$
$$\forall\, p \ni LCTNR\_AF_{p,1,2} = t \textit{ and } LCTNR\_AF_{p,2,2} = v. \quad \text{B-71}$$

The variable *LCMSN* pertains to the specific service and year for which it is calculated.

Market shares of equipment within least-cost behavior segment of replacement decision type:

$$LCMSR_{t,v} = \sum_p TimePrefProp_{s,p,y}, \quad \text{B-72}$$

$$\forall\, p \ni LCTNR\_AF_{p,1,1} = t \textbf{ and } LCTNR\_AF_{p,2,1} = v.$$

The variable *LCMSR* pertains to the specific service and year for which it is calculated.

Equipment market shares within same-fuel behavior segment of new decision type:

$$SFMSN_{t,v} = \sum_p \sum_f \left[TimePrefProp_{s,p,current\ year} * PrevYrFuelShareofService_{r,b,s,f}\right],$$
$$\textbf{for all } p \textbf{ and major fuels } f \textbf{ such that } LCTNR\_SF_{p,f,1,2} = t, and\ LCTNR\_SF_{p,f,2,2} = v,$$
$$\textbf{and for the value of } s \textbf{ pertaining to } t \textbf{ and } v. \quad \text{B-73}$$

The variable SFMSN pertains to the specific building type and region for which it is calculated.

Equipment market shares within same-fuel segment of replacement decision type:

$$SFMSR_{t,v} = \sum_p \sum_f \left[TimePrefProp_{s,p,current\ year} * ReplacementFuelShareofService_{r,b,s,f}\right],$$
$$\textbf{for all } p \textbf{ and major fuels } f \textbf{ such that } LCTNR\_SF_{p,f,1,1} = t, and\ LCTNR\_SF_{p,f,2,1} = v,$$
$$\textbf{and for the value of } s \textbf{ pertaining to } t \textbf{ and } v. \quad \text{B-74}$$

The variable SFMSR pertains to the specific building type and region for which it is calculated.

Equipment market shares within same-technology segment of new decision type:

$$STMSN_{t,v} = \left[\sum_{\forall\, p \ni LCVNRST_{p,t,2}=v} TimePrefProp_{s,p,y}\right] * \left[\sum_{\forall\, v'} PrevYrTechShareofService_{r,b,s,t,v'}\right]. \quad \text{B-75}$$

The variable *STMSN* pertains to the specific building type and region for which it is calculated.

Equipment market shares within same-technology behavior segment of replacement decision type:

$$STMSR_{t,v} = \left[\sum_{\forall\, p \ni LCVNRST_{p,t,1}=v} TimePrefProp_{s,p,y}\right] * \left[\sum_{\forall\, v'} ReplacementShareofService_{r,b,s,t,v'}\right]. \quad \text{B-76}$$

The variable *STMSR* pertains to the specific building type, region, and service for which it is calculated.

Equipment market shares within new decision type, consolidated across behavior segments:

$$MS_{b,s,1,t,v} = BehaviorShare_{s,b,1,1} * LCMSNR_{t,v} + BehaviorShare_{s,b,1,2} * SFMSN_{t,v} + BehaviorShare_{s,b,1,3} * STMSN_{t,v}, \qquad \text{B-77}$$

where the subscript *1* appearing in *MS* and the next to last subscript of *BehaviorShare* represents the decision type, and, in this case, corresponds to the *new* decision. The last subscript of *BehaviorShare* represents the behavior rule.

Equipment market shares within replacement decision type, consolidated across behavior segments:

$$MS_{b,s,2,t,v} = BehaviorShare_{s,b,2,1} * LCMSNR_{t,v} + BehaviorShare_{s,b,2,2} * SFMSR_{t,v} + BehaviorShare_{s,b,2,3} * STMSR_{t,v}, \qquad \text{B-78}$$

where the subscript *2* appearing in *MS* and the next to last subscript of *BehaviorShare* represents the decision type, and, in this case, corresponds to the *replacement* decision. The last subscript of *BehaviorShare* represents the behavior rule.

Annualized cost of retaining existing equipment, relative to retrofitting:

$$ACE_{t,v,y} = TechCost_{t,v,2} * CapacityFactor_{r,b,s} - RetroCostFract_{t,v} * KEqCost(t,v,y,\text{CAP}) * \frac{EffectHurdleAdj}{1-(1+EffectHurdleAdj)^{-TechLife_{t,v}}} + ShellEffFactor_1 * \frac{ConvFactor}{TechEff_{r,s,t,v}} * \frac{CapacityFactor_{r,b,s}}{\frac{1}{2}TechLife_{t,v}} * \sum_{y'=y}^{y+\frac{1}{2}*TechLife_{t,v}-1} Xprice_{f_t,r,y},$$

where

$\mathbf{ConvFactor = 8.76\ for\ all\ services\ except\ lighting}$;

$\mathbf{ConvFactor = 0.03345^{-1}/TechCRI(\mathit{r,s,t,v})\ for\ \mathit{s} = lighting}$; and

$\mathbf{f_t = fuel\ used\ by\ technology\ \mathit{t}.}$ B-79

The variable *ACE* refers to the specific building type and service for which it is calculated. The variable *EffectHurdleAdj* is the effective hurdle or implicit discount rate for the current fuel, census division, service, and year, as calculated in equation B-63. The variable *ShellEffFactor* is involved in the calculation only for space heating and space cooling and is set to *ShellHeatFactor* or *ShellCoolFactor* as appropriate. Because only the relative costs of choices are important within each building, the equation above is divided by *CapacityFactor*, which has the same value for all equipment providing a certain service in each building type and census division, to simplify the calculation actually evaluated by the model. $LCTRetAF_{p,t,v,1}$ represents the technology class with the least annualized cost for retrofit decisions, and $LCTRetAF_{p,t,v,2}$ represents the technology model with the least annualized cost for retrofit decisions. The conversion factor for all end uses other than lighting annualizes the fuel costs. For lighting, the conversion factor converts fuel costs from NEMS in dollars per MMBtu to dollars per kilowatt-year.

Equation B-79 also includes an adjustment for *TechCRI* (the lighting color rendering index), which reduces the *effective efficiency* of low-CRI lighting technologies and renders them less attractive relative to higher-CRI options.

Identify least-cost fuel alternative for retrofit decision, following least-cost behavior (stage 1):

$\boldsymbol{Find\ t', v' \ni AnnualCostTech_{p,t',v'} \leq ACE_{t,v,p}}$.
If there is such a *t'* and *v'*, then $\boldsymbol{LCTRetAF_{p,t,v,1} = t', LCTRetAF_{p,t,v,2} = v'}$.
Otherwise, $\boldsymbol{LCTRetAF_{p,t,v,1} = t\ and\ LCTRetAF_{p,t,v,2} = v}$. B-80

Identify least-cost equipment for retrofit decision using same fuel as selected in stage 1, following least-cost behavior (stage 2):

$\boldsymbol{Find\ t', v' \ni AnnualCostTechAdj_{p,t',v'} \leq ACE_{t,v,p}}$ **such that *t'* shares the same fuel as** $\boldsymbol{LCTRetAF_{p,t,v,l}}$.
If there is such a *t'* and *v'*, then $\boldsymbol{LCTRetAF_{p,t,v,1} = t', LCTRetAF_{p,t,v,2} = v'}$.
Otherwise, $\boldsymbol{LCTRetAF_{p,t,v,1} = t\ and\ LCTRetAF_{p,t,v,2} = v}$. B-81

Identify least-cost retrofit alternative for same-fuel behavior:

$\boldsymbol{Find\ t', v' \ni AnnualCostTechAdj_{p,t',v'} \leq ACE_{t,v,p}}$.
If there is such a *t'* and *v'*, then $\boldsymbol{LCTRetSF_{p,t,v,1} = t'\ and\ LCTRetSF_{p,t,v,2} = v'}$. B-82
Otherwise, $\boldsymbol{LCTRetSF_{p,t,v,1} = t \quad and\ LCTRetSF_{p,t,v,2} = v}$.

Identify least-cost retrofit alternative for same-technology behavior, when optional retrofitting is allowed:

$\boldsymbol{Find\ v' \ni AnnualCostTechAdj_{p,t,v'} \leq ACE_{t,v,p}, \forall v'}$.
If there is such a *v'*, then $\boldsymbol{LCVRetST_{p,t,v} = v'}$.
Otherwise, $\boldsymbol{LCVRetST_{p,t,v} = v}$. B-83

Equipment market shares within least-cost behavior segment of retrofit decision type:

$$\boldsymbol{LCMSRet_{p,t,v} = \sum_{t',v',p}\left[TimePrefProp_{s,p,current\ year} * SurvivingShareofService_{t',v'}\right],}$$
$$\boldsymbol{\forall t', v' \ni LCTRetAF_{p,t',v',1} = t;\ LCTRetAF_{p,t',v',2} = v;\ \forall\ p,} \quad \text{B-84}$$

where *s* represents the service corresponding to technology *t* and vintage *v.*

Equipment market shares within same-fuel behavior segment of retrofit decision type:

$$\boldsymbol{SFMSRet_{t,v} = \sum_{t',v',p}\left[TimePrefProp_{s,p,current\ year} * SurvivingShareofService_{t',v}\right],} \quad \text{B-85}$$

$$\forall t', v' \ni LCTRetSF_{p,t',v',1} = t;\ LCTRetSF_{p,t',v',2} = v;\ \forall p.$$

$LCTRetSF_{p,t,v,1}$ represents the technology class with the least annualized cost for retrofit decisions, and $LCTRetSF_{p,t,v,2}$ represents the technology model with the least annualized cost for retrofit decisions.
s represents the service corresponding to technology *t* and vintage *v.*

Equipment market shares within same-technology behavior segment of retrofit decision type:

$$STMSRet_{t,v} = \sum_{v',p}\left[TimePrefProp_{s,p,current\ year} * SurvivingShareofService_{t,v'}\right],$$
$$\forall v' \ni LCVRetST_{p,t,v'} = v;\ \forall p, if\ STRetBehav = 1.$$
$$SurvivingShareofService_{t,v'}, if\ STRetBehav = 0. \qquad \text{B-86}$$

$LCVRetST_{p,t,v'}$ represents the technology model with the least annualized cost for retrofit decisions.
s represents the service corresponding to technology *t* and vintage *v.*

Equipment market shares within retrofit decision type, consolidated across behavior segments:

$$MS_{b,s,3,t,v} = BehaviorShare_{s,b,3,1} * LCMSRet_{t,v} + BehaviorShare_{s,b,3,2} * SFMSRet_{t,v} + BehaviorShare_{s,b,3,3} * STMSRet_{t,v}, \qquad \text{B-87}$$

where the subscript *3* appearing in *MS* and the next to last subscript of *BehaviorShare* represents the decision type, and, in this case, corresponds to the *retrofit* decision. The last subscript of *BehaviorShare* represents the behavior rule. *MS* is recalculated for each census division, as are the other variables in this equation.

Heat pump market shares of space cooling service demand:

$$MS_{b,s=SPCool,d,t',v'} = \frac{MS_{b,s=SPHeat,d,t,v} * SD_{s=SPHeat,d} * \frac{DegreeDays_{s=SPCool,r,current\ year}}{DegreeDays_{s=SPHeat,r,current\ year}}}{SD_{s=SPCool,d}}, if\ SD_{s=SpCool,d} > 0.$$
$$MS_{b,s=SPCool,d,t',v'} = 0, if\ SD_{s=SpCool,d} = 0,$$
$$for\ t, v \in \{Heat\ pumps\ for\ space\ heating\},$$
$$\mathbf{t', v' = same\ equipment\ as}\ t, v\ \mathbf{except\ for\ space\ cooling};\ \text{and}$$
$$\mathbf{SD_{s=s,d} = service\ demand\ for\ service}\ s\ \mathbf{and\ decision\ type}\ d. \qquad \text{B-88}$$

Amount of cooling service demand satisfied by heat pumps:

$$HeatPumpCoolingSD_d = SD_{s=SpCool,d} * \sum_{t,v \in \{Heat\ pumps\ for\ space\ cooling\}} MS_{b,s=SpCool,d,t,v}. \qquad \text{B-89}$$

$$Normalizer_d = \sum_{t,v \in \{space\ cooling\ equip\ other\ than\ heatpumps\}} MS_{b,s=SpCool,d,t,v}. \qquad \text{B-90}$$

HeatPumpCoolingSD and *Normalizer* pertain to the specific building type for which they are calculated.

Adjusted market shares of space cooling equipment other than heat pumps:

$$\boldsymbol{MS_{b,s=SpCool,d,t,v}} = \frac{\boldsymbol{MS_{b,s=SpCool,d,t,v}}}{\boldsymbol{Normalizer_d}} * \frac{\left(\boldsymbol{SD_{s=SpCool,d}} - \boldsymbol{HeatPumpCoolingSD_d}\right)}{\boldsymbol{SD_{s=SpCool,d}}},$$
$$\boldsymbol{t}, \boldsymbol{v} \in \{\boldsymbol{space\ cooling\ equipment\ other\ than\ heat\ pumps}\}. \quad \text{B-91}$$

Fuel shares by fuel, decision type, service, building, and census division:

$$\boldsymbol{FS_{r,b,s,d,f}} = \sum_t \sum_v \left[\boldsymbol{MS_{b,s,d,t,v,[r]}} * \boldsymbol{FuelbyTech_{t,f}}\right], \boldsymbol{where\ FuelbyTech_{t,f} = 1\ if\ t\ uses\ f}.$$
$$\boldsymbol{FS_{r,b,s,d,f}} = \boldsymbol{0}, \boldsymbol{elsewhere},$$
$$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}. \quad \text{B-92}$$

Average equipment efficiency by fuel, decision type, service, building, and census division:

$$\boldsymbol{AE_{r,b,s,d,f}} = \frac{\boldsymbol{FS_{r,b,s,d,f}}}{\sum_{t,v}\left[\frac{\boldsymbol{MS_{b,s,d,t,v}} * \boldsymbol{FuelbyTech_{t,f}}}{\boldsymbol{TechEff_{r,s,t,v}}}\right]}, \boldsymbol{if\ t\ and\ v\ exist\ s.t.\ MS_{b,s,d,t,v}} * \boldsymbol{FuelbyTech_{t,f}} \neq \boldsymbol{0}.$$
$$\boldsymbol{0}, \boldsymbol{elsewhere},$$
$$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}. \quad \text{B-93}$$

Fuel shares by fuel, end use, building, and census division:

$$\boldsymbol{FuelShareofService_{r,b,s,f}} = \frac{\boldsymbol{NSD_{r,b,s,y}} * \boldsymbol{FS_{r,b,s,1,f}}}{\boldsymbol{TSD_{r,b,s,y}}} + \frac{\boldsymbol{RSD_{r,b,s,y}} * \boldsymbol{FS_{r,b,s,2,f}}}{\boldsymbol{TSD_{r,b,s,y}}} + \frac{\boldsymbol{SSD_{r,b,s,y}} * \boldsymbol{FS_{r,b,s,3,f}}}{\boldsymbol{TSD_{r,b,s,y}}},$$
$$\boldsymbol{where\ TSD_{r,b,s,y}} > \boldsymbol{0}.$$
$$\boldsymbol{FuelShareofService_{r,b,s,f}} = \boldsymbol{0}, \quad \boldsymbol{elsewhere},$$
$$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\},$$
$$\boldsymbol{y = current\ year}. \quad \text{B-94}$$

TSD $_{r,b,s,y}$ is the total service demand, defined as *SSD* $_{r,b,s,y}$ + *RSD* $_{r,b,s,y}$ + *NSD* $_{r,b,s,y}$ (in other words, existing service demand + replacement service demand + new-building service demand).

Equipment market shares by equipment, end use, building, and census division:

$$\boldsymbol{TechShareofService_{r,b,s,t,v}} = \frac{\boldsymbol{NSD_{r,b,s,y}} * \boldsymbol{MS_{r,b,s,1,t,v}}}{\boldsymbol{TSD_{r,b,s,y}}} + \frac{\boldsymbol{RSD_{r,b,s,y}} * \boldsymbol{MS_{r,b,s,2,t,v}}}{\boldsymbol{TSD_{r,b,s,y}}} + \frac{\boldsymbol{SSD_{r,b,s,y}} * \boldsymbol{MS_{r,b,s,3,t,v}}}{\boldsymbol{TSD_{r,b,s,y}}},$$
$$\boldsymbol{where\ TSD_{r,b,s,y}} > \boldsymbol{0}.$$
$$\boldsymbol{TechShareofService_{r,b,s,t,v}} = \boldsymbol{0}, \boldsymbol{elsewhere},$$
$$\forall\ \boldsymbol{t}, \boldsymbol{v},$$
$$\boldsymbol{y = current\ year}. \quad \text{B-95}$$

Average equipment efficiency by fuel, end use, building, and census division:

$$\boldsymbol{AverageEfficiency_{r,b,s,f}} = \frac{\boldsymbol{FuelShareofService_{r,b,s,f}}}{\sum_{t,v}\left[\frac{\boldsymbol{TechShareofService_{r,b,s,2,v} * FuelbyTech_{t,f}}}{\boldsymbol{TechEff_{r,s,t,v}}}\right]},$$

where t and v exist such that $\boldsymbol{TechShareofService_{r,b,s,t,v} * FuelbyTech_{t,f} \neq 0}$.

$$\boldsymbol{AverageEfficiency_{r,b,s,f}} = \boldsymbol{0}, \boldsymbol{elsewhere},$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-96

Average equipment efficiency for new decision type by fuel, end use, and census division:

$$\boldsymbol{DecAvgEff_{r,s,1,f,y}} = \frac{\sum_b\left[\boldsymbol{FS_{r,b,s,1,f} * ND_{r,b,s,y}}\right]}{\sum_b\left[\frac{\boldsymbol{FS_{r,b,s,1,f} * NSD_{r,b,s,y}}}{\boldsymbol{AE_{r,b,s,1,f}}}\right]},$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-97

The third subscript of *DecAvgEff* and the fourth subscript of *FS* represent the equipment decision type, *d*. Decision type 1 refers to new equipment.

Average equipment efficiency for replacement decision type by fuel, end use, and census division:

$$\boldsymbol{DecAvgEff_{r,s,2,f,y}} = \frac{\sum_b\left[\boldsymbol{FS_{r,b,s,2,f} * RD_{r,b,s,y}}\right]}{\sum_b\left[\frac{\boldsymbol{FS_{r,b,s,2,f} * RSD_{r,b,s,y}}}{\boldsymbol{AE_{r,b,s,2,f}}}\right]},$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-98

Decision type 2 refers to replacement equipment.

Average equipment efficiency for retrofit decision type by fuel, end use, and census division:

$$\boldsymbol{DecAvgEff_{r,s,3,f,y}} = \frac{\sum_b\left[\boldsymbol{FS_{r,b,s,3,f} * SSD_{r,b,s,y}}\right]}{\sum_b\left[\frac{\boldsymbol{FS_{r,b,s,3,f} * SSD_{r,b,s,y}}}{\boldsymbol{AE_{r,b,s,3,f}}}\right]},$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-99

Decision type 3 refers to retrofit equipment.

Fuel shares within new decision type by fuel, end use, and census division:

$$\boldsymbol{DecFuelShare_{r,s,1,f,y}} = \frac{\sum_b\left[\boldsymbol{FS_{r,b,s,1,f} * NSD_{r,b,s,y}}\right]}{\sum_b \boldsymbol{NSD_{r,b,s,y}}},$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-100

The third subscript of *DecFuelShare* represents decision type, *d*. Decision type 1 refers to new equipment.

Fuel shares within replacement decision type by fuel, end use, and census division:

$$DecFuelShare_{r,s,2,f,y} = \frac{\sum_b [FS_{r,b,s,2,f} * RSD_{r,b,s,y}]}{\sum_b RSD_{r,b,s,y}},$$
$$f \in \{Major\ Fuels\}. \quad \text{B-101}$$

Decision type 2 refers to replacement equipment.

Fuel shares within retrofit decision type by fuel, end use, and census division:

$$DecFuelShare_{r,s,3,f,y} = \frac{\sum_b [FS_{r,b,s,3,f} * SSD_{r,b,s,y}]}{\sum_b SSD_{r,b,s,y}},$$
$$f \in \{Major\ Fuels\}. \quad \text{B-102}$$

Decision type 3 refers to retrofit equipment.

National average equipment efficiency by fuel and end use:

$$CMUSAvgEff_{s,f,y} = \frac{\sum_r \sum_b [FuelShareofService_{r,b,s,f} * TSD_{r,b,s,y}]}{\sum_r \sum_b \sum_{t,v} \left[\frac{TechShareofService_{r,b,s,t,v} * FuelbyTech_{t,f} * TSD_{r,b,s,y}}{TechEff_{r,s,t,v}}\right]},$$
$$s \in \{Major\ Services\}, \{Major\ Fuels\}. \quad \text{B-103}$$

Minor service average efficiency by fuel, end use, building, and census division:

$$AverageEfficiency_{r,b,s,f} = PrevYrAverageEfficiency_{r,b,s,f} * (1 + EffGrowthRate_s),$$
$$s \in \{Minor\ Services\},$$
$$f = electricity. \quad \text{B-104}$$

Minor service average efficiency and fuel share by decision type, fuel, end use, and census division:

$DecAvgEff_{r,s,d,f,y} = AverageEfficiency_{r,s,f}$, for all decision types ***d*** and years ***y***
$DecFuelShare_{r,s,d,f,y} = FuelShrofService_{r,s,f}$, for all decision types ***d*** and years ***y***
$s \in \{Minor\ Services\}$.

B-105

Comparison of three-year average price to base-year price for Price-Induced Technological Change:

$$PriceDelta3_{f,y} = \frac{(Price_{f,11,y} + Price_{f,11,y-1} + Price_{f,11,y-2})/3}{Price_{f,11,Baseyear}},$$
$$f \in \{\ Major\ Fuels\ \}; y > KSTEOYR, \quad \text{B-106}$$

where the subscript *11* represents region *11*, resulting in the national average price for each fuel.

Number of years to shift technology availability based on parameter assumptions for Price-Induced Technological Change:

For all major fuels, in years after the last STEO benchmarking year:

If $IFMAX \leq \frac{(PriceDelta3_{f,y}-1.0)}{0.10}$:

$$Iforward_{f,t,v,y} = IFMAX.$$

If $IFoward_{t,v,y-1} < \frac{(PriceDelta3_{f,y}-1.0)}{0.10} < IFMAX$:

$$Iforward_{f,t,v,y} = \frac{(PriceDelta3_{f,y}-1.0)}{0.10}.$$

If neither of the above two statements is true:

$$Iforward_{f,t,v,y} = Iforward_{t,v,y-1}, \qquad \text{B-107}$$

where *IFMAX* is the user parameter specifying the maximum number of years a technology can potentially be advanced. *IForward* is adjusted to a smaller number of years if its application causes model *v* of technology class *t* to become available before the persistent price increase is projected to occur.

End-use fuel consumption equations

Basic estimate of fuel consumption to meet end-use demands other than lighting:

$$EndUseConsump_{f,s,b,r,y} = \frac{FuelShareofService_{r,b,s,f} * TSD_{r,b,s,y}}{AverageEfficiency_{r,b,s,f}}, if\ AverageEfficiency > 0,$$
$$0, otherwise$$
$$s \neq lighting, f \in \{Major\ Fuels\}. \qquad \text{B-108}$$

Basic estimate of fuel consumption by lighting equipment:

$$EndUseConsump_{f,s,b,r,y} = \frac{FuelShareofService_{r,b,s,f} * TSD_{r,b,s,y}}{AverageEfficiency_{r,b,s,f}} \div 0.03345, \text{ where}$$
$$s = lighting, \qquad \text{B-109}$$

and where 0.033435 GWy/trillion Btu converts units used in lighting to Btu and GWy refers to electricity use in gigawatt-years.

Short-Run Price Elasticity of Demand Function:

$$\boldsymbol{KElast_{f,r,y,s}} = \left(\frac{\boldsymbol{PelCMout_{f,r,y,s}}}{\boldsymbol{PelCMout_{f,r,CBECSyear,s}}}\right)^{\varepsilon_1 * \boldsymbol{EF_1}} * \left(\frac{\boldsymbol{PelCMout_{f,r,y-1,s}}}{\boldsymbol{PelCMout_{f,r,CBECSyear,s}}}\right)^{\varepsilon_1 * \boldsymbol{EF_2}} * \left(\frac{\boldsymbol{PelCMout_{f,r,y-2,s}}}{\boldsymbol{PelCMout_{f,r,CBECSyear,s}}}\right)^{\varepsilon_1 * \boldsymbol{EF_3}},$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$, B-110

where $PelCMout_{f,r,y,s}$ is the price of fuel *f* in census division *r* during year *y* for end-use service *s* (the subscript *s* is only applicable for electricity prices). ε_1 is the elasticity parameter for the short-term price elasticity for census division *r* and service *s*, and EF_1, EF_2, and EF_3 are the distributed lag weights.

Modification of fuel consumption by Price Elasticity and Rebound Effect:

$$\boldsymbol{EndUseConsump_{f,s,b,r,y}} = \boldsymbol{EndUseConsump_{f,s,b,r,y}} * \boldsymbol{KElast_{f,r,y,s}} * \left(\mathbf{1} + \left[\mathbf{1} - \frac{\boldsymbol{AverageEfficiency_{r,b,s,f}}}{\boldsymbol{AverageEfficiencyBASE_{r,b,s,f}}}\right] * \varepsilon_2 * \left(\mathbf{1} + \left[\boldsymbol{ShellEffIndex_{b,r,1}} - \mathbf{1}\right] * \varepsilon_2\right)\right),$$

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$,

$\boldsymbol{s} \in \{\boldsymbol{Space\ Heating}, \boldsymbol{Space\ Cooling}\}$,

evaluated without building shell effect (third term) for
s ∈ (water heating, ventilation, cooking, and lighting),
evaluated without equipment and building shell efficiency effects (second and third terms) f
s ∈ (refrigeration, all office equipment, and other uses), B-111

where ε_2 is the elasticity parameter for the rebound elasticity.

Weather correction for space heating:

$$\boldsymbol{EndUseConsump_{f,s,b,r,y}} = \boldsymbol{EndUseConsump_{f,s,b,r,y}} * \left(\frac{\boldsymbol{DegreeDays_{s,r,y}}}{\boldsymbol{DegreeDays_{s,r,CBECSyear}}}\right),$$

$\boldsymbol{s} \in \{\boldsymbol{Space\ Heating}\}$,

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-112

Weather correction for space cooling:

$$\boldsymbol{EndUseConsump_{f,s,b,r,y}} = \boldsymbol{EndUseConsump_{f,s,b,r,y}} * \left(\frac{\boldsymbol{DegreeDays_{s,r,y}}}{\boldsymbol{DegreeDays_{s,r,CBECSyear}}}\right)^{\mathbf{1.1}},$$

$\boldsymbol{s} \in \{\boldsymbol{Space\ Cooling}\}$,

$\boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}$. B-113

Computation of shares of electricity for end-use adjustment to purchased electricity to account for self-generation:

$$\boldsymbol{ElShr_s = \frac{EndUseConsump_{1,s,b,r,y}}{\sum_s EndUseConsump_{1,s,b,r,y}},} \qquad \text{B-114}$$

where *1* is the fuel subscript representing electricity. *ElShr* is recalculated for each building type *b*, census division *r*, and year *y*.

Deduction of electricity generated by distributed or behind-the-meter generation technologies from purchased electricity demand:

$$\boldsymbol{EndUseConsump_{1,s,b,r,y} = EndUseConsump_{1,s,b,r,y} - \sum_t Trills_{y,r,b,t} * ElShr_s} \qquad \text{B-115}$$

where $Trills_{y,r,b,t}$ is the amount of electricity (in trillion Btu) generated during year *y* in census division *r*, building type *b*, by distributed technology *t*. Optionally, the code allows for scenarios that attribute behind-the-meter PV generation to service specific end uses (e.g. space cooling, ventilation, lighting, and miscellaneous electric loads) as show in equation B-116. This option is not enabled for the Reference case or core side cases. Instead, PV generation is treated the same as other DG and CHP technologies—electricity generated from behind-the-meter or distributed technologies offsets purchased electricity demand, without regard to the specific end-use served.

Optional deduction of electricity generated by distributed PV systems from purchased electricity demand for specific end-use services:

$$\boldsymbol{EndUseConsump_{1,2,b,r,y} = EndUseConsump_{1,2,b,r,y} - 0.12 * Trills_{y,r,b,1},}$$
$$\boldsymbol{EndUseConsump_{1,4,b,r,y} = EndUseConsump_{1,4,b,r,y} - 0.13 * Trills_{y,r,b,1},}$$
$$\boldsymbol{EndUseConsump_{1,6,b,r,y} = EndUseConsump_{1,6,b,r,y} - 0.16 * Trills_{y,r,b,1},}$$
$$\boldsymbol{EndUseConsump_{1,10,b,r,y} = EndUseConsump_{1,10,b,r,y} - 0.59 * Trills_{y,r,b,1},} \qquad \text{B-116}$$

where $Trills_{y,r,b,1}$ is the amount of electricity (in trillion Btu) generated during year *y* in census division *r*, building type *b*, by distributed PV systems (*t=1*). In the example scenario specified in the optional code, electricity generated by PV systems is assumed to affect space cooling (*s=2*), ventilation (*s=4*), lighting (*s=6*), and miscellaneous electric loads (*s=10*). This option is not enabled for the Reference case or core side cases.

Reduction in space and water heating consumption because of combined heat and power (CHP):

$$\boldsymbol{EndUseConsump_{f,l,b,r,y} = EndUseConsump_{f,1,b,r,y} - \sum_{\forall t\ using\ fuel\ f} SHBtu_{y,r,b,t},}$$
$$\boldsymbol{EndUseConsump_{f,3,b,r,y} = EndUseConsump_{f,3,b,r,y} - \sum_{\forall t\ using\ fuel\ f} HWBtu_{y,r,b,t},} \qquad \text{B-117}$$

$\boldsymbol{f} \in \{\boldsymbol{natural\ gas}, \boldsymbol{distillate}\}.$

SHBtu$_{y,r,b,t}$ and *HWBtu*$_{y,r,b,t}$ are the amounts of space and water heating (in trillion Btu) provided during year *y* in census division *r*, building type *b*, by distributed resources (see equations B-186 and B-187). The second subscript in *EndUseConsump* refers to service, and 1 represents space heating, and 3 represents water heating.

Addition of consumption of major fuels by distributed generation and CHP technologies:

$$\boldsymbol{EndUseConsump_{f,10,b,r,y} = EndUseConsump_{f,10,b,r,y} + \sum\nolimits_{\forall t\ using\ fuel\ f} FuelUsage_{y,r,b,t}},$$
$$\boldsymbol{f} \in \{\boldsymbol{natural\ gas}, \boldsymbol{distillate}\}, \qquad \text{B-118}$$

where *FuelUsage*$_{y,r,b,t}$ is the amount of fuel *f* used (in trillion Btu) during year *y* in census division *r*, building type *b*, by distributed resources (see equation B-185). The subscript 10 of *EndUseConsump* refers to consumption by the *Other* service.

Consumption of fuels to provide district services, by census division, building type, fuel, and service:

$$\boldsymbol{DistServConsump_{r,b,s,f,y}} = \boldsymbol{DistServSteamEUI_{r,b,s}} * \left(\boldsymbol{SurvFloorTotal_{r,b,y}} + \boldsymbol{CMNewFloorSpace_{r,b,y}}\right) * \left(\frac{\boldsymbol{DistServFuelShr_{r,f,s}}}{\boldsymbol{DistServBoilerEff_f}}\right) * \boldsymbol{10^{-3}},$$
$$\boldsymbol{s} \in \{\boldsymbol{District\ Services}\};\ \boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}. \qquad \text{B-119}$$

Weather correction and short-term price elasticity for district services consumption:

$$\boldsymbol{DistServConsump_{r,b,s,f,y} = DistServConsump_{r,b,s,f,y} * KElast_{f,r,y,s}} * \frac{\boldsymbol{DegreeDays_{s,r,y}}}{\boldsymbol{DegreeDays_{s,r,CBECSyear}}},$$
$$\boldsymbol{s} \in \{\boldsymbol{District\ Services}\};\ \boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\},$$
$$\boldsymbol{evaluated\ without\ weather\ effect\ for\ s} \in (\boldsymbol{water\ heating}). \qquad \text{B-120}$$

U.S. total fuel consumption to provide district services (quadrillion Btu):

$$\boldsymbol{CMUSDistServ_{s,f,y}} = \left[\sum\nolimits_{\boldsymbol{r}} \sum\nolimits_{\boldsymbol{b}} \boldsymbol{DistServConsump_{r,b,s,f,y}}\right] * \boldsymbol{10^{-3}},$$
$$\boldsymbol{s} \in \{\boldsymbol{District\ Services}\};\ \boldsymbol{f} \in \{\boldsymbol{Major\ Fuels}\}. \qquad \text{B-121}$$

Addition of district services fuel use to end-use fuel consumption:

$$\boldsymbol{EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} + DistServConsump_{r,b,s,f,y}}, \qquad \text{B-122}$$

$f \in \{Major\ Fuels\}$.

Total fuel consumption across end-use services:

$$FinalEndUseCon_{f,b,r,y} = \sum_s EndUseConsump_{f,s,b,r,y},$$
$$f \in \{Major\ Fuels\}. \qquad \text{B-123}$$

Unbenchmarked fuel consumption projection by census division and building type:

$$UnBenchedCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y},$$
$$f \in \{Major\ Fuels\}. \qquad \text{B-124}$$

U.S. total fuel consumption by end use (quadrillion Btu):

$$CMUSConsump_{s,f,y} = \left[\sum_r \sum_b EndUseConsump_{f,s,b,r,y}\right] * 10^{-3},$$
$$f \in \{Major\ Fuels\}. \qquad \text{B-125}$$

U.S. average minor service equipment efficiency by end use and fuel:

$$CMUSAvgEff_{s,f,y} = \frac{\sum_r \sum_b \left[FuelShareofService_{r,b,s,f} * TSD_{r,b,s,y}\right]}{CMUSConsump_{s,f,y} * 10^3},$$
$$\forall\ s \in \{Minor\ Services\};\ f \in \{Major\ Fuels\}. \qquad \text{B-126}$$

Calculation of minor fuel consumption:

$$FinalEndUseCon_{f,b,r,y} = e^{\left(MinorFuelAlpha_{f,r} + \log(price) x MinFuelBeta_{f,r}\right)} * 10^{-3} * \left(SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}\right),$$
$$\forall\ f \in \{Minor\ Fuels\}, \qquad \text{B-127}$$

where $MinFuelAlpha_{f,r}$ is the regression intercept for fuel *f* in census division *r*, and $MinFuelBeta_{f,r}$ is the regression coefficient (price elasticity) for fuel *f* in census division *r*

Unbenchmarked consumption of fuels across building types, by census division:

$$CMFinalUnbenchUse_{f,r,y} = \sum_b UnBenchedCon_{f,b,r,y},$$
$$\forall\ f \in \{Major\ Fuels\}. \qquad \text{B-128}$$

Consumption of fuels across end uses, including CHP and district services, by census division:

$$CMFinalEndUse_{f,r,y} = \sum_b FinalEndUseCon_{f,b,r,y},$$
$$f \in \{Major\ Fuels, Minor\ Fuels, Renewable\ Fuels\}. \qquad \text{B-129}$$

U.S. total consumption by building type, across end uses, including CHP, district services, and solar thermal:

$$CMFinalEndUseCon_{b,y} = \sum_r \sum_f FinalEndUseCon_{f,b,r,y},$$
$$\forall\, f \in \{\, Major\ Fuels, Minor\ Fuels, Renewable\ Fuels\,\}.$$

$$CMFinalEndUseCon_{b,y} = \sum_r \sum_f FinalEndUseCon_{f,b,r,y} + \sum_r \sum_s \frac{SolarRenewableContrib_{r,s,y}}{CMnumBldg},$$
$$\forall\, s \in \{Space\ Heating, Water\ Heating\}. \quad \text{B-130}$$

Benchmarking equations

Difference between projection and SEDS fuel consumption data (*SEDS mistie*) for historical years:

$$SEDSMistie_{f,r} = \sum_{y=MSEDYR-3}^{MSEDYR+1} CMSEDS_{f,r,y} - CMFinalEndUse_{f,r,y},$$
$$f \in \{Major\ Fuels, Minor\ Fuels\};\ f \neq Motor\ Gasoline. \quad \text{B-131}$$

$$SEDSMistie_{f,r} = \sum_{y=MSEDYR-1}^{MSEDYR+1} CMSEDS_{f,r,y} - CMFinalEndUse_{f,r,y},$$
$$f = Motor\ Gasoline. \quad \text{B-132}$$

Non-building fuel use projection for historical years:

$$CMNonBldgUse_{f,r,y} = CMSEDS_{f,r,y} - CMFinalEndUse_{f,r,y},$$
$$y \leq MSEDYR + 1. \quad \text{B-133}$$

Difference between projected electricity use with SEDS non-building component and STEO forecast:

$$STEOMistie_{f,r,[y]} = CMSEDS_{f,r,y} - \langle CMFinalEndUse_{f,r,y} + SEDSMistie_{f,r,[MSEDYR+1]} + \left(\frac{MC_{COMMFLSP_{r,b=l,y}} - MC_{COMMFLSP_{r,l,MSEDYR+1}}}{MC_{COMMFLSP_{r,b=l,MSEDYR+1}}}\right) * \left|SEDSMistie_{f,r,[,b=l,MSEDYR+1]}\right| \rangle,$$
$$MSEDYR + 1 < KSTEOYR,$$
$$f \in \{Electricity\}. \quad \text{B-134}$$

SEDS-based component of non-building fuel use of electricity after last year of available SEDS data:

$$\boldsymbol{CMNonBldgUse_{f,r,y}} = \boldsymbol{SEDSMistie_{f,r}} + \left(\frac{\boldsymbol{MC\_COMMFLSP_{r,b=l,y}} - \boldsymbol{MC\_COMMFLSP_{r,b=l,MSEDYR+1}}}{\boldsymbol{MC\_COMMFLSP_{r,b=l,MSEDYR+1}}}\right) * \left|\boldsymbol{SEDSMistie_{f,r}}\right|,$$

$$\boldsymbol{y} > \boldsymbol{MSEDYR+1},$$
$$\boldsymbol{f} \in \{\boldsymbol{Electricity}\}. \quad \text{B-135}$$

Projected electricity consumption for water and telecom services:

$$\boldsymbol{WaterServicesElQ_{r,y}} = \left(\boldsymbol{MiscK3_{water}}\Delta_y{}^{3} + \boldsymbol{MiscK2_{water}} * \Delta_y{}^{2} + \boldsymbol{MiscKl_{water}} * \Delta \boldsymbol{y} + \boldsymbol{MiscK0_{water}}\right) * \frac{\boldsymbol{MC_{NP_{r,y}}}}{\boldsymbol{MC_{NP_{11,y}}}}. \quad \text{B-136}$$

$$\boldsymbol{TelecomServicesElQ_{r,y}} = \left(\boldsymbol{MiscK3_{telecom}}\Delta_y{}^{3} + \boldsymbol{MiscK2_{telecom}} * \Delta_y{}^{2} + \boldsymbol{MiscKl_{telecom}} * \Delta \boldsymbol{y} + \boldsymbol{MiscK0_{telecom}}\right) * \frac{MC_{NP_{r,y}}}{MC_{NP_{11,y}}}, \quad \text{B-137}$$

where $\Delta y \equiv y - CBECSyear$, the number of years between the current year and the commercial base year, $MC\_NP_{r,y}$ is the projected population in census division *r* with *r* =11 representing the U.S. total, and *MiscK3, MiscK2, MiscK1,* and *MiscK0* are constant values. Values for equation coefficients and constants associated with each MEL are in Appendix A.

Projected growth in electricity consumption for water and telecom services after last year of available SEDS data:

$$\boldsymbol{WaterServicesQGrowth}_{[r],[y]} = \boldsymbol{WaterServicesElQ_{r,y}} - \boldsymbol{WaterServicesElQ_{r,MSEDYR+1}}. \quad \text{B-138}$$

$$\boldsymbol{TelecomServicesQGrowth}_{[r],[y]} = \boldsymbol{TelecomServicesElQ_{r,y}} - \boldsymbol{TelecomServicesElQ_{r,MSEDYR+1}}. \quad \text{B-139}$$

Addition of projected water and telecom services growth to SEDS-based component of non-building fuel use of electricity:

$$\boldsymbol{CMNonBldgUse_{f=l,r,y}} = \boldsymbol{CMNonBldgUse_{f=l,r,y}} + \boldsymbol{WaterServicesQGrowth}_{[r],[y]} + \boldsymbol{TelecomServicesQGrowth}_{[r],[y]}. \quad \text{B-140}$$

Growth in electricity use for water and telecom services is added because the SEDS-based component of non-building electricity consumption includes use for water and telecom services in the last year of available SEDS data.

Difference between projected natural gas, distillate fuel oil, or minor fuel consumption (including SEDS non-building component) and STEO forecast:

$$\boldsymbol{STEOMistie_{f,r,[y]} = CMSEDS_{f,r,y} - \left(CMFinalEndUse_{f,r,y} + SEDSMistie_{f,r}\right),}$$
$$\boldsymbol{MSEDYR + 1 < y \leq KSTEOYR,}$$
$$\boldsymbol{f \in \{Natural\ Gas, Distillate, Minor\ Fuels\}.} \quad \text{B-141}$$

SEDS-based component of non-building natural gas, distillate fuel oil, or residual fuel oil consumption:

$$\boldsymbol{CMNonBldgUse_{f,r,y} = SEDSMistie_{f,r},}$$
$$\boldsymbol{y > MSEDYR + 1,}$$
$$\boldsymbol{f \in \{Natural\ Gas, Distillate, Minor\ Fuels\}.} \quad \text{B-142}$$

Limit STEO benchmarking adjustments to cases where the STEOMistie is greater in absolute value than 2% of the STEO forecast (activated if the STEOBM2pct or KSTEOCLS switch equals 1):

$$\boldsymbol{If\ \left|STEOMistie_{f,r,[y]}\right| \leq 0.02 * CMSEDS_{f,r,y}:}$$
$$\boldsymbol{STEOMistie_{f,r,[y]} = 0.}$$
$$\boldsymbol{If\ STEOMistie_{f,r,[y]} > 0.02 * CMSEDS_{f,r,y}:}$$
$$\boldsymbol{STEOMistie = STEOMistie_{f,r,[y]} - 0.02 * CMSEDS_{f,r,y}.}$$
$$\boldsymbol{If\ STEOMistie_{f,r,[y]} < -0.02 * CMSEDS_{f,r,y}:}$$
$$\boldsymbol{STEOMistie = STEOMistie_{f,r,[y]} + 0.02 * CMSEDS_{f,r,y},}$$
$$\boldsymbol{MSEDYR + 1 < y \leq KSTEOYR.} \quad \text{B-143}$$

Optional benchmarking to STEO forecast for years where STEO data are available:

$$\boldsymbol{CMNonBldgUse_{f,r,y} = CMNonBldgUse_{f,r,y} + STEOMistie_{f,r,[y]},}$$
$$\boldsymbol{if\ STEOBM = 1\ and\ ComSTEOBM = 1.}$$
$$\boldsymbol{CMNonBldgUse_{f,r,y} = unchanged, otherwise,}$$
where
$$\boldsymbol{MSEDYR + 1 < y \leq KSTEOYR,}$$
$$\boldsymbol{f \in \{Major\ Fuels, Minor\ Fuels\}.} \quad \text{B-144}$$

Optional decay factor to apply to final STEO mistie for optional benchmarking to STEO after last year of STEO data:

$$\boldsymbol{STEOTieDecayFactor_{[y]} = 1, if\ DecayBM = 0.} \quad \text{B-145}$$

$$TEOTieDecayFactor_{[y]} = 1 - \frac{(y - KSTEOYR)}{(FirstNonBenchYr - KSTEOY)}, if\ DecayBM = 1.$$
$$STEOTieDecayFactor_{[y]} = 0, if\ DecayBM = 1\ and\ y \geq FirstNonBenchYr,$$

where *FirstNonBenchYr* is converted from a calendar year to a year index before use. The decay factor is applied to projections for all fuels.

Optional STEO-based component of non-building fuel consumption projected after last year of available STEO data:

$$CMNonBldgUse_{f,r,y} = CMNonBldgUse_{f,r,y} + STEOMistie_{f,r,[KSTEOYR]} * STEOTieDecayFactor_{[y]},$$
$$if\ STEOBM = 1.$$
$$CMNonBldgUse_{f,r,y} = unchanged, otherwise. \quad \text{B-146}$$

Final benchmarked projected fuel consumption by fuel, census division, and year:

$$CMFinalEndUse_{f,r,y} = CMFinalEndUse_{f,r,y} + CMNonBldgUse_{f,r,y},$$
$$f \in \{Major\ Fuels, Minor\ Fuels\}. \quad \text{B-147}$$

Distributed generation equations

Projections of distributed generation penetration are based on the results of cash-flow simulations carried out at a finer level of geographic detail, relative to other NEMS commercial model results. The choice of higher-resolution *niches* was made because solar resources as well as electricity prices can vary substantially within a census division. Penetration estimates based on census division average insolation and census division average prices will fail to represent opportunities for niche penetration. The niche concept was extended by including additional variables:

- Solar opportunities (roof area per square foot)
- Average wind speed in the niche for distributed wind turbines
- Natural gas prices relative to the census division average for natural gas-fired technologies

The confluence of renewable resources and energy prices determines niche opportunities for penetration of these types of energy investments.

For each year in a NEMS run, a 30-year cash-flow analysis is evaluated for each potential distributed generation investment. Simulations are carried out by census division, building type, building size category, and niche. The division/building type/size/niche calculations are made separately for each of the modeled distributed generation technologies where additional penetration might be expected.

The niche information is developed from the CBECS Public Use Files, coupled with solar and wind resource maps produced by the National Renewable Energy Laboratory. The average solar insolation and average wind speeds are developed by overlaying CBECS climate zones by census division and either the solar or wind resource maps. The niches are first defined by insolation levels, and then average wind speed is developed for each solar niche. There are currently 26 solar niches. The number of niches within a census division depends on solar insolation variability—generally more niches are required for census divisions that have greater latitudinal dispersion. Within the insolation niches, commercial floorspace area is divided into bins by electricity price relative to the division average price, by decile. The resulting combined solar resource/electricity price bins define the 260 niches (26 times 10) where either insolation or the electricity price varies.

Even though the niches are defined based on solar resource and electricity rate level, additional information is developed from CBECS for use in the cash flow and penetration calculations for photovoltaics, wind, and natural gas-fired technologies. For each niche, the following variables are included:

- Solar insolation
- Average wind speed
- The floorspace share of census division floorspace area
- Average electricity price relative to the census division average
- Average natural gas price relative to the census division average
- Roof area as a percentage of floorspace area (because rooftop PV is the only distributed solar technology currently modeled)

Each distributed generation technology is indexed by an annual vintage that aligns with the NEMS model year, and so this technique allows technical characteristics (such as efficiency or cost) or tax incentives to vary annually over the entire NEMS horizon. For ease of notation, subscripts denoting the technology, region, building type, size category, and niche are generally suppressed until the interface with NEMS is described beginning with equation B-181. Exceptions to the subscript suppressing are made in a few instances before equation B-181 when beneficial for clarity.

In any NEMS projection year, the total number of cash flow simulations performed will equal the number of census divisions (r = 9) times the number of modeled building types (b = 11) times the number of building size categories (s = 6) times the number of solar insolation niches (n = 26) times the number of electric rate levels per niche (l = 10) times the number of distributed technologies modeled (t = 11). An uppercase *Y* denotes years in the cash-flow analysis to distinguish cash flow simulation years from NEMS model years (which are denoted with a lowercase *y*). Lowercase *y* also represents the annual technology vintages because technology vintages have a one-to-one correspondence with NEMS projection years. Even though the cash-flow model is run by region, building type, size category, and niche for each distributed generation technology and for each NEMS model year, many of the cash flow variables are *reusable*. For such variables, as well as variables that accumulate by year but do not have an explicit year dimension, the convention of placing the implicit dimension in brackets–such as [y]–will be followed. Year 1 of the cash-flow analysis is the purchase year, during which no savings or expenses other than the loan down payment occur. Year 2 is the first year of operation, or the *base year*. Year 3 is when any tax credits are assumed to be received and is also the start of the system *degradation* calculations described below.

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

$$\boldsymbol{AdjCost_{t,[y]}} = \boldsymbol{MIN}\langle \boldsymbol{MaxCost_{t,[y]}}, \boldsymbol{C_{0,t}} * \boldsymbol{CumShip_{t,[y]}}^{-\boldsymbol{\beta_t}} \rangle, \qquad \text{B-148}$$

where $C_{0,t}$ and β_t are technology-specific learning cost parameters, and $CumShip_{t,[y]}$ represents cumulative shipments in megawatts for NEMS model year *y*, for residential and commercial buildings and utility installations combined (supplied via the global interface).

Equipment cost scale adjustment:

$CalcKW_{[t],[r],[b],[s],[n],[l],[y]}$ represents the generating capacity of the selected scale of a particular distributed generation technology customized to the average building characteristics for the census region, building type, size class, solar niche, and rate level niche for a particular year. For each technology, a maximum and minimum size are specified as well as a scale adjustment factor, $ScaleFac_t$. Each technology also has a *typical* size system with generating capacity denoted by $KW_{t,y}$ and typical cost and performance data characterized for each year. $ScaleFac_t$ is a positive constant that determines how steeply costs decline as economies of scale (from larger-sized units) are realized. In the formula below, EXP represents the exponentiation in base *e*, and LN is logarithm base *e*.

$$\boldsymbol{AdjCost2_{[t],\dots[y]}} = \boldsymbol{EXP}\begin{bmatrix} \boldsymbol{LN}\left(\boldsymbol{AdjCost_{[t],[y]}}\right) \\ -\boldsymbol{ScaleFac_t} \cdot \boldsymbol{LN}\left(\boldsymbol{CalcKW_{[t],\dots[y]}} / \boldsymbol{KW_{t,y}}\right) \end{bmatrix} * \boldsymbol{CalcKW_{[t],\dots[y]}}. \qquad \text{B-149}$$

$CalcKW_{[t],\dots,[y]}$ is allowed to vary by building type, size, and niche, and the target maximum size is enough to serve the building's annual electricity requirements, subject to maximum and minimum size constraints for the technology being evaluated. In the case of solar photovoltaics, commercial roof area considered to be suitable for installation depends on building size, based on a 2016 NREL report.[33] Available roof area is developed from roof-area-to-floorspace ratios estimated from CBECS and provided as part of the niche inputs. The modules are also assumed to be placed at *latitude tilt* (in other words, the tilt of the panels corresponds to the latitude of the site to approximately maximize annual insolation by using a fixed-position mount), which requires about twice the roof area needed for minimum rack spacing on flat roofs. On sloped roofs, modules are assumed to be close enough to be flush-mounted so that a one-square-foot module requires the roof area of one square foot. An estimated 75% of commercial roof area is flat, so on average, for a certain amount of available commercial roof area,

[33] Gagnon, Pieter, Robert Margolis, Jennifer Melius, Caleb Phillips, and Ryan Elmore. 2016. "Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment." National Renewable Energy Laboratory Technical Report (NREL/TP-6A20-65298).

75%*2.0+25%*1.0 (or 1.75) square feet of roof area are required to mount a one-square-foot module. Based on roof area constraints, the kW capacity of the maximum module area is calculated:

$$\boldsymbol{CalcKW}_{[t],\ldots[y]} = \frac{\boldsymbol{CBECS12AvgSqft}_{r,b,s} \cdot \boldsymbol{RoofAreatoSqftRatio}_{r,b,n,l} * \boldsymbol{pctPVSuitable}_{s}}{\boldsymbol{SqftperKW}_{[y]} * 1.75}. \qquad \text{B-150}$$

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

In this equation, the subscript *n* signifies solar niche, while the last subscript of *RoofAreatoSqftRatio* represents the rate level.

Installed equipment cost:

$$\boldsymbol{EqCost}_{[t],\ldots[y]} = \left(\boldsymbol{AdjCost}_{[t],\ldots[y]} + \boldsymbol{InstCost}_{t,y}\right) * \boldsymbol{CalcKW}_{[t],\ldots[y]}. \qquad \text{B-151}$$

Initial outlay cost:

$$\boldsymbol{DownPay}_{[t],\ldots[y]} = \boldsymbol{CalcEqCost}_{[t],\ldots[y]} * \boldsymbol{DownPayPct}. \qquad \text{B-152}$$

Annual levelized payment calculation:

$$\boldsymbol{Payment}_{[t],\ldots[y]} = \left[\boldsymbol{CalcEqCost}_{[t],\ldots[y]} - \boldsymbol{DownPay}_{[t],\ldots[y]}\right] * \frac{\boldsymbol{IntRate}}{1 - (1 + \boldsymbol{IntRate})^{-\boldsymbol{Term}}}, \qquad \text{B-153}$$

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

Outlays for capital relating to down payments and borrowing costs:

$$\boldsymbol{Outlay}_{[t],\ldots[y],Y-1} = \boldsymbol{DownPay}_{[t],\ldots[y]},$$
$$\boldsymbol{Outlay}_{[t],\ldots[y],1<Y\leq Term} = \boldsymbol{Payment}_{[t],\ldots[y]},$$
$$\boldsymbol{Outlay}_{[t],\ldots[y],Y>Term} = 0. \qquad \text{B-154}$$

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

$$\boldsymbol{Prin}_{[t],\ldots[y],Y} = \boldsymbol{Payment}_{[t],\ldots[y]} - \boldsymbol{IntAmt}_{[t],\ldots[y],Y}, \qquad \text{B-155}$$

where $Prin_{[t],\ldots,[y],Y}$ is the amount of principal paid on the loan in each year *Y* of the cash-flow analysis and is also used to determine the loan balance for the next year of the analysis. It is computed as the difference between the levelized payment and the interest paid: $IntAmt_{[t],\ldots,[y],Y}$ is the interest paid for the loan in each year of the analysis. This variable is a component of the tax deduction calculation. It is computed as last year's ending principal balance, $LoanBal_{[t],\ldots,[y],Y-1}$, times the interest rate on the loan. $LoanBal_{[t],\ldots,[y],Y}$ is the principal balance of the loan for each year of the analysis. The loan balance decreases over time:

$$\boldsymbol{LoanBal_{[t],\ldots[y],Y} = LoanBal_{[t],\ldots[y],Y-1} - Prin_{[t],\ldots[y],Y}}. \quad \text{B-156}$$

$TaxCredit_{[t],\ldots,[y],Y}$ is the allowed tax credit and can vary both by technology and vintage for distributed generation investments favored by the tax code. For equipment that qualifies for a federal investment tax credit (ITC), we do not apply any safe harbor provisions. We assume all systems will be installed within the same calendar year as the relevant ITC rate.

The credit is assumed to be collected in Year 3 of the cash-flow analysis. Per current laws and regulations, as outlined in EIA's assumptions to the *Annual Energy Outlook,* a permanent 10% tax credit for photovoltaics is available under EPACT92 (the maximum credit in any one year is $25,000, but *unused* credit can be carried forward to future years). the Bipartisan Budget Act of 2018 (P.L. 115-123) extended ITC provisions for geothermal heat pumps, qualified fuel cell and microturbine equipment, combined heat and power, and qualified small wind through 2021. The Consolidated Appropriations Act, 2021 (P.L. 116-260) extended the phase out of ITCs for distributed generation equipment by an additional two years. Commercial ITCs drop to 10% after 2023. The Inflation Reduction Act of 2022 (P.L. 117-169), IRA, allows a 30% tax credit for solar PV and wind through 2050, and a 6-10% credit for behind-the-meter commercial CHP systems, with potential rate increases if certain conditions are met. We assume a 10% credit through 2024 for CHP systems. The IRA specifies that the credits decrease if the electric power sector meets emissions reduction targets. In CDM, the tax credit incentive is sensitive to whether the electric power sector emission draw down occurs.EPACT92 provides for a shortened tax life of five years for photovoltaics and wind (contrasted with 39.5 years for other distributed generation investments, which are treated as building equipment by the tax code) and allows accelerated depreciation as described below.

$$\boldsymbol{TaxCredit_{[t],\ldots[y],Y} = MAX\langle EqCost_{[t],\ldots[y]} * TaxCreditPct_{[t],[y]}, TaxCreditMax_{[t],[y]}\rangle, if\ Y = 3.}$$
$$\boldsymbol{TaxCredit_{[t],\ldots[y],Y} = 0, if\ Y \neq 3.} \quad \text{B-157}$$

$Depr_{[t],\ldots,[y],Y}$ is the computed depreciation amount. Based on current tax law, the depreciation method is set to *straight line* (constant depreciation) for all technologies except PV and wind, which are allowed accelerated depreciation using a *double-declining balance* formula with the $Dep_{[t],[y]}$ set to 200. The model will also allow accelerated depreciation for other distributed generation technologies if such treatment becomes part of the tax code, controlled via technology and vintage-specific input parameters in the input file, kgentk.txt. The straight-line depreciation amount is the same for all years during the tax life of the investment. In contrast, accelerated depreciation varies from year to year. If the useful life of the equipment exceeds the tax life (or if accumulated depreciation payments reach total investment cost in the case of accelerated methods) then $Depr_{[t],\ldots,[y],Y}$ is zero for all subsequent years. Current law for distributed generation investments requires only a 50% reduction in the basis for any tax credits received.

Straight-line depreciation amount:

$$\boldsymbol{Depr}_{[t],\dots[y],Y} = \frac{\left(\boldsymbol{EqCost}_{[t],\dots[y]} - 0.5 * \boldsymbol{TaxCredit}_{[t],\dots[y]}\right)}{\boldsymbol{TaxLife}_{[t],[y]}}. \qquad \text{B-158}$$

Accelerated depreciation calculation:

$$\boldsymbol{Depr}_{[t],\dots[y],Y} = \boldsymbol{MAX}\left\langle \frac{\boldsymbol{Basis}_{[Y]}}{\boldsymbol{TaxLife}_{[t],[y]}} * \frac{\boldsymbol{Dep}_{[t],[y]}}{\mathbf{100}}, \frac{\left(\boldsymbol{EqCost}_{[t],\dots[y]} - 0.5 * \boldsymbol{TaxCredit}_{[t],\dots[y]}\right)}{\boldsymbol{TaxLife}_{[t],[y]}} \right\rangle, \qquad \text{B-159}$$

where the $Basis_{[Y]}$ is calculated according to the following:

$$\boldsymbol{Basis}_{[Y]} = \left(\boldsymbol{EqCost}_{[t],\dots[y]} - \mathbf{0.5} * \boldsymbol{TaxCredit}_{[t],\dots[y],2}\right) \boldsymbol{for\ Y = 2},$$
$$\boldsymbol{Basis}_{[Y]} = \boldsymbol{Basis}_{[Y-1]} - \boldsymbol{Depr}_{[t],\dots[y],Y}\ \boldsymbol{for\ Y \geq 3}, \qquad \text{B-160}$$

and $Tax\ Credit_{[t],\dots,[y]}$ is the minimum of the total credit less the credit claimed to date and $25,000.

The first term in equation B-159 represents the accelerated depreciation amount, and the second term represents the straight line amount. A *crossover* year occurs where the straight-line amount exceeds the accelerated amount. For this year and beyond, the allowed depreciation becomes the larger straight-line amount. Finally, in the final year of an investment's *depreciable lifetime*, the amount calculated in equation B-159 is further limited to be no greater than the remaining $Basis_{[Y]}$.

Annual kilowatthours generated by technology:

$AnnualKWH_{[t],[r],[b],[s],[n],[l],[y]}$ represents the base level of annual system kilowatthour generation for a new system for the specific technology, census division, building type, building size, and CBECS solar niche and rate level being analyzed.

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

$$\boldsymbol{AnnualKWH}_{[t=1],\dots,[y]} = \left(\boldsymbol{ElEff}_{t=1,y} * \boldsymbol{SolarIns}_{r} * \boldsymbol{SQFTperKW}_{y} * \boldsymbol{LossFac}_{t=1,y}\right) * \boldsymbol{CalcKW}_{[t=1],[y]}. \qquad \text{B-161}$$

The variable *CalcKW* represents a system size chosen either based on available roof area or by annual electricity requirements, whichever is less. Photovoltaic penetration is also assumed suitable for only a portion of commercial building roof area as a result of orientation issues, shading, and other roof and building constraints; the assumed share of rooftop area suitable for PV varies by building size.

The parenthetical expression represents the kilowatthours generated by a 1 kilowatt system, so this amount is then multiplied by system kilowatts to yield the annual generation amount. Solar insolation,

$SolarIns_{r,n}$, varies by niche within census division (the number of niches per division varies and depends on solar resource variability) and is expressed in daily kilowatthours falling on a square meter area. The insolation value is converted to an annual kilowatthour per square foot area and then adjusted for module square footage and the assumed electrical efficiency of the PV technology. Finally a loss factor (the percentage of the generation reaching the outlet) allows further adjustment of annual kilowatthours available to the building by accounting for downstream electrical losses. The variable for the estimated PV array square footage for a 1 kilowatt system, $SQFTperKW_y$, depends on the efficiency of the system (the higher the efficiency, the lower the required square footage for a 1 kilowatt module) as follows:

$$\boldsymbol{SQFTperKW_y = 77.0 * \frac{0.14}{ElEff_{1,y}}}. \qquad \text{B-162}$$

Note that the higher the efficiency, the smaller the square footage that will be required for a 1 kilowatt system.

Distributed wind turbines (technology, *t=11*): Annual generation is determined by turbine size, efficiency, and average wind speeds as follows:

$$\boldsymbol{AnnualKWH_{[t=11],\ldots,[y]} = \left(\frac{ElEff_{t=11,y}}{ElEff_{t=11,1}} * (0.0645 - 0.0670 * MpS + 0.0210 * MpS^2 - 0.0011 * MpS^3)\right) * LossFac_{t=1,y} * CalcKW_{[t=11],\ldots,[y]}}, \qquad \text{B-163}$$

where *MpS* denotes average wind speed in meters per second.

Similar to solar photovoltaics, the variable *CalcKW* represents a system size chosen based on annual electricity requirements; however, there is no analog to the roof area limitation for photovoltaics. Distributed wind turbine penetration is also assumed appropriate and suitable for only 10% of commercial buildings, as a result of permitting issues and site limitations.

Non-renewable technologies (*t≠1, t≠11*): Annual system generation for a 1 kilowatt unit is determined by hours-of-use multiplied by an availability factor and a loss factor. Annual generation is determined by multiplying the amount for a 1 kilowatt system by system capacity:

$$\boldsymbol{AnnualKWH_{[t=11],\ldots,[y]} = \left(OperHours_t * Avail_{t,y} * LossFac_{t,y}\right) * CalcKW_{[t],\ldots[y]}\ for\ t \neq 1}, \qquad \text{B-164}$$

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

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

Fuel consumption for distributed generation technologies:

Fuel consumption for *fired* generation technologies is denoted by the variable $FuelInput_{[t],\ldots,[y]}$ and is calculated in MMBtu of the input fuel used by the technology:

$$\boldsymbol{FuelInput_{[t],\ldots[y]} = \frac{0.003412 * OperHours_t * Avail_{t,y}}{ElEff_{t,y}} * CalcKW_{[t],\ldots[y]}}. \qquad \text{B-166}$$

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

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

$$\boldsymbol{BTUWasteHeat_{[t],\ldots[y]} = \left(FuelInput_{[t],\ldots[y]} - 0.003412 * AnnualKWH_{[t],\ldots[y]}\right) * WhRecovery_{t,y}}. \qquad \text{B-167}$$

The amount of available waste heat is partitioned into water heating and space heating end-use services up to the average consumption for those end uses by census division, building type (*b*), and size category (*s*):

$$\boldsymbol{WaterHtgMMBtu_{[t],[r],[b],[s],[y]} = MIN\langle BTUWasteHeat_{[t],\ldots[y]}, CBECS12AvgSqft_{b,s} * ComEUI_{r,b,s=3,f=2}\rangle}. \qquad \text{B-168}$$

If the distributed generation equipment provides more waste heat than the average water heating requirements, then any residual is assumed to be provided as space heating up to a maximum of the average space heating requirements. Any amount of waste heat generated beyond the average water and space heating requirements is assumed to not be used to offset end-use fuel requirements. Natural gas-fired technologies are expected to be primarily responsible for growth in combined heat and power over the projection period, allowing the simplifying assumption that these systems will satisfy water and space heating requirements otherwise met with natural gas-fired end-use equipment.

$$\boldsymbol{SpaceHtgMMBtu_{[t],[r],[b],[s],[y]} = MIN\langle BTUWasteHeat_{[t],\ldots[y]} - WaterHtgMMBtu_{[t],\ldots[y]}, CBECS12AvgSqft_{b,r,s} * ComEUI_{r,b,s=1,f=2}\rangle}. \qquad \text{B-169}$$

Net fuel cost:

$BaseYrFuelCost_{[t],...,[y]}$ is the initial fuel cost for operating the generation technology net of savings stemming from displaced water heating or space heating. It is calculated from the current NEMS fuel price converted into the same year constant dollars as the technology capital costs. This price is then scaled based on the natural gas price in the solar (*n*) and electricity rate (*l*) niches relative to the census division natural gas price:

$$\begin{aligned} \boldsymbol{BaseYrFuelCost}_{[t],...[y],[l],[y]} &= \left(\boldsymbol{FuelInput}_{[t],...[y]} - \boldsymbol{WaterHtgMMBtu}_{[t],[y]} - \boldsymbol{SpaceHtgMMBtu}_{[t],[y]}\right) \\ &* \boldsymbol{NGRateScalar}_{r,n,l} * \boldsymbol{FuelPrice}_{r,y}. \end{aligned} \qquad \text{B-170}$$

$FuelCost_{[t],...,[y],Y}$ is the nominal dollar value fuel cost for the technology net of any water heating and space heating cost savings from using waste heat:

$$\boldsymbol{FuelCost}_{[t],...[y],Y} = \boldsymbol{BaseYrFuelCost}_{[t],...[y]} * (\mathbf{1} + \boldsymbol{inflation})^{(Y-2)}. \qquad \text{B-171}$$

Value of electricity savings calculations:

$ValESaveBase_{[t],...,[y]}$ represents the calculated value of generated electricity for the initial year of the cash flow simulation. This value is further adjusted to account for inflation and generation efficiency degradation in a later calculation described below.

Case 1: Photovoltaics

If generation is less than average electricity usage for the building type, (that is, $AnnualKWH_{[t],...,[y]} \leq ElecAvgKWH_{b,s}$), then savings are valued at the air-conditioning price (this price is used instead of the average electricity price because of the *coincidence* of air-conditioning loads and photovoltaic module generation), scaled based on the electricity price in the rate niche relative to the census division price:

$$\boldsymbol{ValESaveBase}_{[t],...,[r],[n],[l],[y]} = \begin{bmatrix} \boldsymbol{PelCMout}_{r,y,s=2} * \mathbf{0.003412} * \boldsymbol{RateScalar}_{r,n,l} \\ + \boldsymbol{EPRPSPR}_{y} * \mathbf{0.001} * \boldsymbol{RPS}_{t} \end{bmatrix} * \boldsymbol{AnnualKWH}_{[t],...,[y]}. \qquad \text{B-172}$$

In the above equation, the factor 0.003412 converts the NEMS commercial electricity price from dollars per MMBtu to dollars per kilowatthour. The factor 0.001 converts the NEMS renewable portfolio standard credit price, $EPRPSPR_y$, from dollars per megawatthour (MWh) to dollars per kilowatthour. RPS_t may vary depending on renewable portfolio standard (RPS) legislation. For example, if the credit is received, the scalar is set to a value greater than zero (for example, for triple credits, the scalar is 3). Because RPS credits often have a last year, or *sunset* year, the cash flow simulation also tracks the calendar year of each of the simulated years and zeros out the credit if the calendar year exceeds the sunset year. Finally, the factor $RateScalar_{r,n,l}$ converts the NEMS electricity price for census division (*r*) into a price for the solar niche (*n*)/rate level (*l*) combination.

If generation exceeds average usage, then the excess kilowatthours are sold to the grid at the marginal price for utility purchases ($PelME_{r,y}$):

$$\begin{aligned} \boldsymbol{ValESaveBase}_{[t],\ldots,[y]} &= \mathbf{0.003412} \\ &* \begin{bmatrix} \boldsymbol{PelCMout}_{r,y,s=2} * \boldsymbol{RateScalar}_{r,n,l} * \boldsymbol{ElecAvgKwh}_{b,s} \\ + \boldsymbol{PelME}_{r,y} * \left(\boldsymbol{AnnualKWH}_{[t],\ldots,[y]} - \boldsymbol{ElecAvgKwh}_{b,s}\right) \end{bmatrix} + \mathbf{0.001} * \boldsymbol{RPS}_{t,y} \\ &* \boldsymbol{EPRPSPR}_{y} * \boldsymbol{AnnualKWH}_{[t],\ldots,[y]}. \end{aligned} \quad \text{B-173}$$

Case 2: All other technologies

The air-conditioning price, $PelCMout_{r,y,s=2}$, is replaced by $PelCM_{r,y}$, the average electricity price, in Equations B-172 and B-173.

$ValESave_{[t],\ldots,[y],Y}$ is the nominal dollar (inflated) value of $ValESaveBase_{[t],\ldots,[y]}$ with adjustment for output degradation:

$$\begin{aligned} \boldsymbol{ValESave}_{[t],\ldots,[y],Y} &= \boldsymbol{ValElecSaveBase}_{[t],\ldots,[y]} * (\mathbf{1} + \boldsymbol{inflation})^{(Y-2)} \\ &* \left(\mathbf{1} - \boldsymbol{Degradation}_{[t],[y]}\right)^{(Y-2)}. \end{aligned} \quad \text{B-174}$$

Maintenance cost calculations:

$MaintCost_{[t],\ldots,[y],Y}$ is the calculated nominal dollar cost of maintenance for the specific technology and vintage being analyzed. $MaintCostBase_{[t],\ldots,[y]}$ is the annual maintenance cost per kilowatt, and $IntervalCst_{[t=1],[y]}$ is the *interval* maintenance cost for inverter replacement per kilowatt if the technology being evaluated is a photovoltaic system (in other words, technology index 1). $IntervalCst_{[t=1],[y]}$ is non-zero only if the cash-flow model year, *Y*, is an inverter replacement year based on the replacement interval (*iIntervalYrs*) for photovoltaic system vintage, *y*.

$$\begin{aligned} \boldsymbol{MaintCost}_{[t],\ldots,[y],Y} &= \left(\boldsymbol{MaintCostBase}_{[t],\ldots,[y]} + \boldsymbol{IntervalCst}_{[t-1],[y]} * \boldsymbol{kW}_{[t],[y]}\right) \\ &* (\mathbf{1} + \boldsymbol{inflation})^{(Y-2)}. \end{aligned} \quad \text{B-175}$$

Deductible expenses for commercial income taxes:

$$\begin{aligned} \boldsymbol{TaxDeduct}_{[t],\ldots,[y],Y} &= \begin{pmatrix} \boldsymbol{IntAmt}_{[t],\ldots,[y],Y-1} - \boldsymbol{Depr}_{[t],\ldots,[y],Y-1} - \boldsymbol{MaintCost}_{[t],\ldots,[y],Y-1} + \\ \boldsymbol{FuelCost}_{[t],\ldots,[y],Y-1} - \boldsymbol{ValElecSave}_{[t],\ldots,[y],Y-1} \end{pmatrix} \\ &* \boldsymbol{TaxRate} + \boldsymbol{TaxCredit}_{[t],\ldots,[y],Y}. \end{aligned} \quad \text{B-176}$$

Cash flows:

$NetCashFlow_{[t],\ldots,[y],Y}$ is defined as the energy and tax savings less expenditures on capital, fuel, and maintenance:

$$\boldsymbol{NetCashFlow}_{[t],\ldots,[y],Y} = \boldsymbol{ValElecSave}_{[t],\ldots,[y],Y} + \boldsymbol{TaxDeduct}_{[t],\ldots,[y],Y} - \boldsymbol{OutLay}_{[t],\ldots,[y],Y} - \boldsymbol{FuelCost}_{[t],\ldots,[y],Y} - \boldsymbol{MaintCost}_{[t],\ldots,[y],Y}\ . \qquad \text{B-177}$$

Internal rate of return:

$IRR_{[t],\ldots,[y]}$ is computed from the stream of annual $NetCashFlow_{[t],\ldots,[y],Y}$. This calculation is based on an iterative Gauss-Sidel search that finds the discount rate that makes the net present value of the stream of cash flows equal to zero. The convergence criterion is for the calculated IRR to have changed less than 0.0005 from the previous iteration. In the event that convergence is not achieved after 100 iterations, the IRR is set to zero. The final IRR is passed on to the next step.

Real-valued simple payback calculation:

$SimplePayback_{[t],[y]}$ is the number of years required for the investment to pay back and is used in the next step to model penetration. If the IRR from the step above is greater than zero, payback is calculated as follows:

$$\boldsymbol{SimplePayback}_{[t],\ldots,[y]} = \boldsymbol{min}\langle \mathbf{29}, \boldsymbol{log}(\mathbf{2})/(\boldsymbol{log}\left(\mathbf{1} + \boldsymbol{IRR}_{[t],\ldots,[y]}\right)\rangle. \qquad \text{B-178}$$

In the event that the IRR is zero or non-positive, *SimplePayback* is set to its maximum of 29 years.

Maximum penetration:

$$\boldsymbol{MaxPen}_{[t],\ldots,[y]} = \boldsymbol{min}\left(\frac{\boldsymbol{PenParm}_t}{\boldsymbol{SimplePayback}_{[t],\ldots,[y]}}, \mathbf{0.9}\right). \qquad \text{B-179}$$

$PenParm_t$ varies by technology and represents the assumed maximum possible penetration achievable for a given technology with a one-year payback period. Because $SimplePayback_{[t],\ldots,[y]}$ is a real-valued number, it can potentially achieve values of less than one. For a $SimplePayback_{[t],\ldots,[y]}$ of 0.5 years, with a $PenParm_t$ of 0.3, $MaxPen_{[t],\ldots,[y]}$ is 60%. $MaxPen_{[t],\ldots,[y]}$ is assumed to be capped at 90%, even with a simple payback significantly less than one year.

Easing of interconnection limitations:

$$\boldsymbol{Inxdecay}_{r,y} = \boldsymbol{MIN}\,\langle \mathbf{1.0}, \boldsymbol{Inx} \ + \ (\mathbf{1.0} - \boldsymbol{Inx}_r) * \frac{\boldsymbol{y} - \boldsymbol{Inxfy}}{\boldsymbol{Inxly} - \boldsymbol{Inxfy}}\rangle. \qquad \text{B-180}$$

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

Bass diffusion formula:

For a given value of $SimplePayBack_{[t],\ldots,[y]}$, penetration in NEMS follows a Bass diffusion function. Penetration in NEMS model year *[y]* is an increasing function of *y*.

$$\boldsymbol{Pen}_{[t],[y]} = \boldsymbol{MaxPen}_{[t],\ldots,[y]} * \frac{\boldsymbol{c} * \left(\mathbf{1} - \boldsymbol{e}^{-\boldsymbol{b}[\boldsymbol{y}-\boldsymbol{AssumedStartYr}(\boldsymbol{t})]}\right)}{\mathbf{1} + \boldsymbol{a}\boldsymbol{e}^{-\boldsymbol{b}[\boldsymbol{y}-\boldsymbol{AssumedStartYr}(\boldsymbol{t})]}}. \quad \text{B-181}$$

Parameter *c* determines the proportion of the assumed maximum possible penetration ($MaxPen_{[t],\ldots,[y]}$) that is achieved over time. Parameters *a* and *b* influence how quickly penetration asymptotically approaches the maximum. *AssumedStartYr(t)* is technology-specific and is estimated based on historical data; it reflects the first year each distributed technology began to penetrate the market.

Outputs to the CDM and NEMS:

Explicit recognition of the census division and building type dimension commences here. $Units_{y,r,b,t}$ denote the accumulated total number of units in NEMS model year (*y*) employing the relevant type of generation technology by census division (*r*) and building type (*b*). It is computed as the sum of the previous year's value ($Units_{y-1,r,b,t}$) plus the current year's total penetration, including additional exogenous penetration (program-driven amounts). The subscripts denoting census division and building type are restored for this section of the documentation to explicitly describe the interface with NEMS.

$Units_{y,r,b,t}$ accumulates the number of projected distributed generation units across CBECS size categories (*s*) for the CBECS solar niches (*n*) and CBECS rate levels (*l*) combinations within each census region:

$$\boldsymbol{Units}_{y,r,b,t} = \boldsymbol{Units}_{y-1,r,b,t} + \sum_{s,n,l}\left[\boldsymbol{Pen}_{[t],[y]} * (\boldsymbol{CMNewFloorSpace}_{r,b,y} + \boldsymbol{SurvFloorTotal}_{r,b,y}) * \frac{\mathbf{10^6}}{\boldsymbol{CBECS12AvgSqft}_{r,b,s}}\right] - \sum_{s,n,l}\left[\boldsymbol{Pen}_{[t],[y-1]} * (\boldsymbol{CMNewFloorSpace}_{r,b,y-1} + \boldsymbol{SurvFloorTotal}_{r,b,y-1}) * \frac{\mathbf{10^6}}{\boldsymbol{CBECS12AvgSqft}_{r,b,s}}\right]. \quad \text{B-182}$$

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

$$\boldsymbol{Trills}_{y,r,b,t} = \boldsymbol{Trills}_{y-1,r,b,t} + \sum_{s,n,l}\left[\begin{matrix}\left(\boldsymbol{Units}_{y,r,b,t} - \boldsymbol{Units}_{y-1,r,b,t}\right) * \boldsymbol{CBECS12FlspcCatShare}_{r,b,s} \\ * \boldsymbol{SqftShare}_{r,n,l} * \boldsymbol{AnnualKWH}_{[t],\ldots[y]} * \mathbf{3412} * \mathbf{10^{-12}}\end{matrix}\right]. \quad \text{B-183}$$

$TrillsOwnUse_{y,r,b,t}$ accumulates total electricity generation for onsite consumption (*own use*) and converts to trillions of Btu. It is the minimum of 1) the average electric consumption of the relevant building type from CBECS and 2) the annual generation.

$$\begin{aligned} \boldsymbol{TrillsOwnUse}_{y,r,b,t} &= \boldsymbol{TrillsOwnUse}_{y-1,r,b,t} \\ &+ \sum_{s,n,l} \begin{bmatrix} \left(\boldsymbol{Units}_{y,r,b,t} - \boldsymbol{Units}_{y-1,r,b,t}\right) * \boldsymbol{CBECS12FlspcCatShare}_{r,b,s} \\ * \boldsymbol{SqftShare}_{r,n,l} \\ * \boldsymbol{min}\langle \boldsymbol{AnnualKWH}_{[t],\ldots[y]}, \boldsymbol{AvgKwh}_{b,s} \rangle * \mathbf{3412} * \mathbf{10^{-12}} \end{bmatrix}. \end{aligned} \quad \text{B-184}$$

FuelUsage$_{y,r,b,t}$ accumulates *FuelInput*$_{[r],[b],[t],[y]}$ and converts from MMBtu to trillion Btu:

$$\boldsymbol{FuelUsage}_{y,r,b,t} = \sum\nolimits_{s,n,l} \begin{bmatrix} \left(\boldsymbol{Units}_{y,r,b,t} - \boldsymbol{Units}_{y-1,r,b,t}\right) * \boldsymbol{CBECS12FlspcCatShare}_{r,b,s} \\ * \boldsymbol{SqftShare}_{r,n,l} * \boldsymbol{FuelInput}_{[r],[b],[s],[t],[y]} * \mathbf{10^{-6}} \end{bmatrix}. \quad \text{B-185}$$

HWBtu$_{y,r,b,t}$ accumulates *WaterHtgMMBtu*$_{[r],[b],[t],[y]}$ and converts to trillion Btu:

$$\boldsymbol{HWBtu}_{y,r,b,t} = \sum\nolimits_{s,n,l} \begin{bmatrix} \left(\boldsymbol{Units}_{y,r,b,t} - \boldsymbol{Units}_{y-1,r,b,t}\right) * \boldsymbol{CBECS12FlspcCatShare}_{r,b,s} \\ * \boldsymbol{SqftShare}_{r,n,l} * \boldsymbol{WaterHtgMMBtu}_{[r],[b],[s],[t],[y]} * \mathbf{10^{-6}} \end{bmatrix}. \quad \text{B-186}$$

SHBtu$_{y,r,b,t}$ accumulates *SpaceHtgMMBtu*$_{[r],[b],[t],[y]}$ and converts to trillion Btu:

$$\boldsymbol{SHBtu}_{y,r,b,t} = \sum\nolimits_{s,n,l} \begin{bmatrix} \left(\boldsymbol{Units}_{y,r,b,t} - \boldsymbol{Units}_{y-1,r,b,t}\right) * \boldsymbol{CBECS12FlspcCatShare}_{r,b,s} \\ * \boldsymbol{SqftShare}_{r,n,l} * \boldsymbol{SpaceHeatingMMBtu}_{[r],[b],[s],[t],[y]} * \mathbf{10^{-6}} \end{bmatrix}. \quad \text{B-187}$$

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

$$\boldsymbol{Invest}_{y,r,b,t} = \left(\boldsymbol{Units}_{y,r,b,t} - \boldsymbol{Units}_{y-1,r,b,t}\right) * \boldsymbol{EqCost}_{[t],\ldots[y]} * \boldsymbol{kw}_t * \mathbf{10^{-6}}. \quad \text{B-188}$$

Appendix C. References

Introduction

This appendix provides a bibliography citing literature used in the theoretical and analytical design, development, implementation, and evaluation of the NEMS CDM. The references supplied here are supplemented by additional detail regarding page citations, both in the body of this report and in the references provided in Appendix A, starting at Table A-1.

References

Al-Sahlawi, M., "The Demand for Natural Gas: A Survey of Price and Income Elasticities," *The Energy Journal*, (Jan 1989).

Arthur D. Little, Inc., *Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings*, ADL reference 72895-00, prepared for U.S. Department of Energy, Office of Building Equipment, January 2002.

Berenyi, E. and R. Gould, *1991 Resource Recovery Yearbook: Directory and Guide*, Government Advisory Associates, 1991.

Bloomquist, R. et al, *District Heating Development Guide: Legal Institutional, and Marketing Issues*, Vol. 1, Washington State Energy Office, October 1988.

Building Design+Construction, *Green Buildings + Climate Change*, Oak Brook, Illinois, November 2008.

"Citicorp Managers Call Efficiency Key to Tenant Draw," *Energy User News*, June 1991, p. 18.

Cowing, T. and D. McFadden, *Microeconomic Modeling and Policy Analysis: Studies in Residential Energy Demand*, Orlando: Academic Press, Inc., 1984.

Data Resources Inc., *Energy Review*, Lexington, Massachusetts, Fall-Winter 1992-1993.

Decision Analysis Corporation of Virginia and Leidos (formerly Science Applications International Corporation), "Alternative Methodologies for NEMS Building Sector Model Development: Draft Report," prepared for EIA under Contract No. DE-AC01-92EI21946, Task 92-009, Subtask 4, Vienna VA, August 1992.

Database of State Incentives for Renewables & Efficiency (DSIRE), http://programs.dsireusa.org/system/program. Raleigh, NC, accessed August 2025.

Electric Power Research Institute, *A Compendium of Utility-Sponsored Energy Efficiency Rebate Programs*, 1987.

Guidehouse, Inc. and Leidos, Inc., *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, prepared for the U.S. Energy Information Administration, April 2021.

ICF International, L.L.C. *Development of Commercial Building Shell Heating and Cooling Load Factors*, prepared for the U.S. Energy Information Administration, February 2018.

ICF International and International District Energy Association, *U.S. District Energy Services Market Characterization: Commercial Data Analysis for EIA's National Energy Modeling System (NEMS)*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, Arlington, VA, January 2018.

Gordon, F., et al., "Use of Commercial Energy Efficiency Measure Service Life Estimates in Program and Resource Planning," *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings, vol. 3, Commercial and Industrial Building Technologies*, Washington, DC, American Council for an Energy Efficient Economy, August 1988.

Hazilla, M. and R. Kopp, "Systematic Effects of Capital Service Price Definition on Perceptions of Input Substitution," *Journal of Business and Economic Statistics*, April 1986.

Lawrence Berkeley National Laboratory, *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States*, Berkley, CA, September 2021.

Leidos, Inc., *Analyze Distributed Generation, Battery Storage, and Combined Heat and Power Technology Data and Develop Performance and Cost Estimates and Analytic Assumptions for the National Energy Modeling System: Final Report*,https://www.eia.gov/analysis/studies/buildings/dg_storage_chp/. Washington, DC, April 2020.

Leidos, Inc., *Trends in Commercial Whole-Building Sensors and Controls*, prepared for U.S. Energy Information Administration, December 2020.

Jackson, J. et al., *The Commercial Demand for Energy: A Disaggregated Approach*, Oak Ridge National Laboratory, April 1978.

Johnson Controls, *2011 Energy Efficiency Indicator: IFMA Partner results*, October 2011.

Kawamoto, K. et al., *Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendixes*, Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, Prepared for DOE, Contract No. DE-AC03-76SF00098, Berkeley CA, February 2001.

KEMA-XENERGY Inc., *Final Report Assessment of the Commercial Building Stock in the Pacific Northwest*, Prepared for Northwest Energy Efficiency Alliance, March 2004.

Komor, P. and R. Katzev, "Behavioral Determinants of Energy Use in Small Commercial Buildings: Implications for Energy Efficiency," *Energy Systems and Policy*, vol. 12, 1988.

Koomey, J., "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," Ph.D. dissertation, University of California at Berkeley, 1990.

Koomey, J., et al., *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector*, Lawrence Berkeley Laboratory, Applied Science Division, Prepared for DOE, Contract No. DE-AC03-76SF00098, Berkeley CA, July 1991.

Koomey, J.G., *Estimating Total Power Consumption by Servers in the U.S. and the World*, Stanford University, CA, February 2007.

Koomey, J.G., *Growth in Data Center Electricity Use 2005 to 2010*, Stanford University, CA, August 2011.

Lamarre, L., "Shaping DSM," *EPRI Journal*, October/November 1991.

Lamarre, L., "New Push for Energy Efficiency," *EPRI Journal*, April/May 1990.

Leidos (formerly Science Applications International Corporation), *Thermal Efficiency Indicators Characterizing Existing Commercial Buildings*, prepared for U.S. Energy Information Administration, December 2008.

Leidos (formerly Science Applications International Corporation), *Data Analysis for Enhanced Representation of Commercial Thermal Shell Efficiency in the Commercial Demand Module*, prepared for U.S. Energy Information Administration, May 2010 (rev. February 2011).

Leidos (formerly Science Applications International Corporation), *Model Documentation of Enhanced Representation of Commercial Thermal Shell Efficiency in the Commercial Demand Module*, prepared for U.S. Energy Information Administration, April 2010.

Lewis, J. and A. Clarke, Easton Consultants, *Replacement Market for Selected Commercial Energy Service Equipment: Topical Report, Phase 1B--Commercial*, Prepared for Gas Research Institute, June 1990.

Lowe, M., *Shaping Cities: The Environmental and Human Dimensions*, Worldwatch Paper 105, October 1991.

Mitchell-Jackson, J., "Energy Needs in an Internet Economy: A Closer Look at Data Centers," Master's Report, University of California at Berkeley, 2001.

National Analysts, Synergic Resources Corp., QEI, Inc., *Residential Customer Preference and Behavior: Market Segmentation Using CLASSIFY*, EPRI EM-5908, Palo Alto CA: EPRI, March 1989.National Renewable Energy Laboratory (NREL), *Annual Technology Baseline*, Golden, CO, 2021.

Navigant Consulting, Inc., and Leidos (formerly Science Applications International Corporation), *Analysis of Commercial Miscellaneous Electric Loads – 2017 Update*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, April 2017

Navigant Consulting, Inc., and Leidos (formerly Science Applications International Corporation), *Analysis and Representation of Miscellaneous Electric Loads in NEMS*, prepared for U.S. Department of Energy, U.S. Energy Information Administration, May 2013

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case*, prepared for U.S. Energy Information Administration, April 2018.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, prepared for U.S. Energy Information Administration, August 2016.

Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Advanced Case Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, prepared for U.S. Energy Information Administration, August 2016.

Navigant Consulting, Inc., "The Leading Edge of New Energy Efficiency and Renewable Energy Technologies Coming to the Market," webinar, September 4, 2014.

Prete, L., J. Gordon, and L. Bromley, "Electric Utility Demand-Side Management," *Electric Power Monthly*, April 1992.

Regional Economic Research, *Commercial End-Use Data Development Handbook: COMMEND Market Profiles and Parameters*, Vol. 1: COMMEND Market Profiles and Model Structure, EPRI EM-5703, April 1988.

Regional Economic Research, *Commercial End-Use Data Development Handbook: COMMEND Market Profiles and Parameters*, Vol. 2: COMMEND Data and Parameter Development Techniques, EPRI EM-5703, April 1988.

Silicon Valley Leadership Group, *Data Center Energy Forecast Final Report*, July 2008.

TIAX, LLC, *Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030*, Reference No. D0366, prepared for U.S. Energy Information Administration, September 2006.

TIAX LLC, *Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type*, prepared for Building Technologies Program, May 2010.

U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518, Washington, DC, U.S. Government Printing Office, May 1992.

U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps to Reduce Greenhouse Gases*, OTA-O-482, Washington, DC, U.S. Government Printing Office, February 1991.

U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States 1990* (110th ed.), Washington, DC, 1990.

U.S. Energy Information Administration, *Assumptions to the Annual Energy Outlook*, January 2020.

U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Public Use Files, May 2016.

U.S. Energy Information Administration, *2003 Commercial Buildings Energy Consumption Survey*, Public Use Files, September 2008.

U.S. Energy Information Administration, *1999 Commercial Buildings Energy Consumption Survey*, Public Use Files, October 2002.

U.S. Energy Information Administration, *1995 Commercial Buildings Energy Consumption Survey*, Public Use Files, February 1998.

U.S. Energy Information Administration, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*, DOE/EIA-0625(95), Washington, DC, October 1998.

U.S. Energy Information Administration, *Commercial Buildings Characteristics 1992*, DOE/EIA-0246(92), Washington, DC, April 1994.

U.S. Energy Information Administration, *Commercial Buildings Consumption and Expenditures 1992*, DOE/EIA-0318(92), Washington, DC, April 1995.

U.S. Energy Information Administration, *Characteristics of Commercial Buildings 1989*, DOE/EIA-0246(89), Washington, DC, June 1991.

U.S. Energy Information Administration, *Commercial Buildings Consumption and Expenditures 1986*, DOE/EIA-0318(86), Washington, DC, May 1989.

U.S. Energy Information Administration, "Estimation of Energy End-Use Intensities," November 2008.

U.S. Energy Information Administration, "Nonutility Power Producers," Electric Power Monthly, April 1992.

U.S. Energy Information Administration, State Energy Data System (SEDS): Consumption, Price, and Expenditure Estimates.

U.S. Environmental Protection Agency, ENERGY STAR Program, *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*, August 2007.

Vine, E., and J. Harris, "Implementing Energy Conservation Programs for New Residential and Commercial Buildings," *Energy Systems and Policy*, vol. 13, no. 2, 1989.

Wharton Economic Forecasting Associates, *Energy Analysis Quarterly*, Winter 1992.

Appendix D. Model Abstract

Introduction

This section gives a brief summary of the Commercial Demand Module and its role within the National Energy Modeling System (NEMS). Specific information on the following topics is provided:

- Model Name
- Model Acronym
- Description
- Purpose of the Model
- Most Recent Update
- Part of Another Model
- Model Interfaces
- Official Model Representative
- Documentation
- Archive Media and Manuals
- Energy System Described
- Coverage
- Modeling Features
- Model Inputs
- Non-DOE Input Sources

- DOE Input Sources
- Computing Environment
- Independent Expert Review Conducted
- Status of Evaluation Efforts by Sponsor

Model name
Commercial Demand Module

Model acronym
CDM

Description
The NEMS CDM is a simulation tool based on economic and engineering relationships that models commercial sector energy demands at the census-division level of detail for 11 distinct categories of commercial buildings. Commercial equipment selections are performed for the major fuels (electricity, natural gas, and distillate fuel oil) and for the major services (space heating, space cooling, water heating, ventilation, cooking, refrigeration, and lighting). The market segment level of detail is modeled using a constrained life-cycle cost minimization algorithm that considers commercial sector consumer behavior and risk-adjusted time preference premiums. The algorithm also models the following minor fuels: residual fuel oil, liquefied petroleum gas, steam coal, motor gasoline, and kerosene; renewable fuel sources: hydroelectric, biomass, including wood and municipal solid waste; waste heat; and other gaseous fuels. Minor services, including office equipment with a separate breakout of computers, miscellaneous electric loads (MELs), and other uses are modeled in less detail than the major services. Distributed generation and combined heat and power are represented using a detailed cumulative positive cash-flow approach to model penetration of distributed resources. Numerous specialized considerations are incorporated, including the effects of changing building shell efficiencies and consumption to provide district services.

Purpose of the model
As a component of NEMS, the Commercial Demand Module generates midterm projections of commercial sector energy demand. The module facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they affect commercial sector energy demand.

Most recent model update
December 2025

Part of another model?
NEMS

Model interfaces
Receives inputs from the Electricity Market Module, Natural Gas Market Module, Liquid Fuels Market Module, Coal Market Module, and Macroeconomic Activity Module within NEMS. Outputs are provided to the Electricity Market Module, Natural Gas Market Module, Liquid Fuels Market Module, Coal Market Module, and Integrating Module.

Energy system described

U.S. commercial-sector energy consumption

Coverage

- Geographic: nine U.S. 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 and frequency: annual through the projection period
- Products: energy consumption including electricity, natural gas, distillate fuel oil, residual fuel oil, liquefied petroleum gas, steam coal, motor gasoline, kerosene, biomass (including wood, municipal solid waste), hydroelectric, waste heat, and other gaseous fuels; commercial floorspace; and end-use stock efficiency
- Economic sectors: 11 commercial building categories: assembly, education, food sales, food services, health care, lodging, large office, small office, mercantile and service, warehouse, and other
- Services: space heating, space cooling, water heating, ventilation, cooking, lighting, refrigeration, computing, office equipment, and MELs

Modeling features

- Model structure: sequential calculation of projected commercial floorspace, service demand, distributed resource penetration, technology choice, and end-use consumption
- Modeling technique: simulation of technology choice by decision type, within a service, within a building and census division, for the current year of the projections; CBECS data used for initial floorspace, market shares, fuel shares, and district service shares; engineering analyses used for initial efficiency estimates
- Special features: technology choice database and simulation technique capable of accommodating an extensive range of policy analyses, including demand-side management capital incentives, tax credits, and equipment efficiency standards; alternative behavioral, financial, and technology assumptions can be implemented

Model inputs

- Commercial sector floorspace growth by census division and building type
- Description of floorspace categorization to enable mapping to DOE sources
- Commercial sector existing equipment characteristics, including typical equipment capacity, installed capital cost, operating and maintenance cost, and expected physical lifetime
- Equipment research and development advances and projected dates of introduction
- Base-year floorspace by census division, building type, building age cohort, and energy-consuming characteristics
- Base-year district service consumption totals and relative shares
- Base-year energy use intensity by census division, building type, and energy service
- Base-year equipment stock characteristics by census division and energy service
- Base-year energy consumption for calculation of non-building consumption to benchmark
- Historical commercial sector quantities of electricity generated by census division, generating fuel, and building type
- Annual consumption of fuels for combined heat and power by census division and building type

- Current status of commercial sector generating facilities
- Projected commercial sector renewable energy demand, by renewable source and energy service
- Parameter inputs for functional equations, including short-run elasticity parameters, building survival parameters, distributed generation penetration, financing and learning parameters, and behavioral parameters

Non-DOE input sources

McGraw-Hill Construction

- Description of floorspace categorization to enable mapping to DOE sources
- Non-residential building construction starts for development of building survival parameters

Leidos, Inc., (formerly Science Applications International Corporation/SAIC)—(reference provided in Appendix C to this report)

- Shell efficiency indexes and heating and cooling factors reflecting current building codes and construction practices relative to the existing building stock in the base year

Navigant Consulting, Inc., and Leidos, Inc., (formerly SAIC) Technical Reports, Arthur D. Little Technical Reports (references provided in Appendix C to this report)

- Commercial sector existing equipment characteristics, including typical equipment capacity, installed capital cost, operating and maintenance cost, and expected physical lifetime, in future years
- Equipment research and development advances and projected dates of model introduction and projections for technology availability in future years

Leidos, Inc., (formerly SAIC) Distributed Generation/CHP Technology Characterizations (references provided in Appendix C to this report)

- Commercial sector current distributed generation technology characteristics, including installed capital cost, operating and maintenance cost, and expected physical lifetime
- Equipment research and development advances and projected dates of model introduction and projections for technology availability in future years

Energy and Environmental Analysis, Inc., and International District Energy Association, District Energy Systems Characterizations (references provided in Appendix C to this report)

- Fuel shares for district services by census division
- System characteristics for district energy systems in the United States including system efficiency (includes both equipment efficiency and distribution losses) and identification of systems providing both district services and combined heat and power

DOE input sources

Commercial Building Energy Consumption Survey (CBECS), characteristics, building-level consumption, and end-use energy consumption

- Base-year floorspace by census division, building type, building age cohort, energy-consuming characteristics, size class
- Base-year district service consumption totals and relative shares
- Base-year EUI by census division, building type, and energy service
- Base-year equipment stock characteristics by census division and energy service
- Base-year electricity and natural gas prices to determine niches for distributed generation calculations
- Base-year energy consumption for calculation of non-building consumption to benchmark and for distributed generation niche calculations

Form EIA-860, *Annual Electric Generator Report*, forms for years 2019–2021

- Historical commercial sector quantities of electricity generated by census division, generating fuel, and building type
- Annual consumption of fuels for combined heat and power by census division and building type
- Current status of commercial sector generating facilities

National Renewable Energy Laboratory (NREL) Interlaboratory Documentation, 1990

- Projected commercial sector renewable energy demand, by renewable source and energy service

Independent expert reviews conducted

Independent expert reviews of the *Commercial Sector Component Design Report*, July 31, 1992, were conducted by David Belzer, Pacific Northwest Laboratory; Richard E. Jones, Office of Building Technologies, Conservation and Renewable Energy; James E. McMahon, Ph.D., Lawrence Berkeley Laboratory; Robert P. Trost, Ph.D., and Inderjit Kundra, Office of Statistical Standards.

Comprehensive reviews of the model documentation were completed by Fred Joutz and Inderjit Kundra, Statistics and Methods Group, in August 2002 and by Robert Trost, Michael Ye, and Inderjit Kundra, Statistics and Methods Group, in September 2006.

Status of evaluation efforts by sponsor

None

Appendix E. Data Quality

Introduction

The NEMS Commercial Demand Module develops projections of commercial sector energy consumption based on the data elements as detailed in Appendix A of this report. The module input data, parameter estimates, and module variables are described in Appendix A, including the transformations, estimation methodologies, and resulting inputs required to implement the module algorithms. The quality of the principal sources of input data is discussed in Appendix E. Information regarding the quality of parameter estimates and user inputs is provided where available.

Quality of input data

Commercial Buildings Energy Consumption Survey (CBECS)

EIA's *Commercial Buildings Energy Consumption Survey* (CBECS) is the principal data source for the NEMS Commercial Demand Module projections of energy consumption. Key information includes initial floorspace levels and age cohorts, appliance stock composition, district service shares, and unbenchmarked base-year end-use consumption. Information about CBECS methodology, data quality (including the kinds of errors associated with sample surveys), estimation of standard errors, and end-use consumption estimation are available on the *Survey Background & Technical Information* overview on our website.

Energy use intensity (EUI) data source

The EUI estimates discussed in Appendix A of this report (referenced in Table A-1) are based on end-use consumption and floorspace data provided in the CBECS public use microdata files. The end-use consumption data are developed using a combination of engineering end-use models and regression approaches. The methodology used to obtain the final base-year end-use estimates and data quality issues are addressed in *Estimation of Energy End-Use Consumption* within the CBECS Technical Information section.

Technology characterization data sources

The Navigant Consulting and Leidos (formerly Science Applications International Corporation) data sources used to develop technology characterization profiles for the NEMS Commercial Demand Module do not discuss data quality.

Historical energy consumption data: State Energy Data System (SEDS)

SEDS provides estimated energy consumption for the domestic commercial sector. Much of the SEDS published information is developed from data collected at the state level, and maintaining a reliable time series of consistent consumption data from the state sources is difficult. Some of the consumption estimates provided in SEDS are based on a variety of proxy measures, selected primarily based on availability, applicability, continuity, and consistency. These general considerations, along with the fuel-specific considerations discussed in the SEDS documentation, render it impossible to develop meaningful numerical estimates of overall errors associated with the published SEDS data.

User-defined parameters

The principal user-defined parameters in the Commercial Demand Module are the initial proportions of commercial consumers that behave according to each of the seven risk-adjusted time preference premium segments and the three behavior rules described in the body of this report. The risk-adjusted time preference premiums are developed based on analysis of survey and utility data as described below. The behavior rules represent the proportion of consumers following the least-cost, same-fuel, and same-technology rules. These parameters are designed to be calibration parameters, and as such, they are available to align model results with observed historical consumption results and analysts' expectations.

The initial behavior rule proportions are estimated by building type and decision type to utilize relationships between the different types of decision makers and different types of decisions. For existing buildings (replacement and retrofit decision types), the decision makers are divided into government, private sector companies occupying self-owned building space, and private sector companies occupying rented building space. For new buildings, decision makers are divided into organizations building space for their own occupancy and speculative developers building space for sale upon completion. These proportions are developed by building type based on the interpretation of several qualitative descriptions of energy efficiency-related decision-making as described in Appendix A (referenced in Table A-1).

The actual assumptions for the behavior rule proportions associated with government, private sector companies occupying self-owned building space, organizations building space for their own occupancy, and speculative developers are provided in Table E-4 by decision type. Data quality analysis was not performed in the data sources providing this information; as a result, building type and decision type parameters may be uncertain.

Risk-adjusted time preference premium distribution

The literature surveyed during the initial development of the premium distribution provides five quantified distributions of commercial sector consumer payback requirements. These studies vary considerably, which reflects the uncertainty in this area. These studies have been converted to consumer risk-adjusted time preference interest rate premiums and averaged to yield a risk-adjusted time preference premium distribution that is used in the NEMS Commercial Demand Module. This distribution has been adjusted for the base year through the projection period to reflect legislation affecting government purchasing behavior and to incorporate findings from surveys that examine perceptions of energy efficiency and green building practices. We further researched behavioral economics, including methodological research, literature surveys, and previously convened a technical workshop in 2013 to focus on these issues and their specific implications for NEMS end-use modeling.

Insufficient studies are available to completely disaggregate consumer discount rates by census division or by end use. As documented in the published data sources, the variance of each estimate between the studies was far greater than the differences by end use or region. Therefore, we originally applied a single distribution to all technologies and all census divisions.

The distributions from the five studies of commercial sector payback requirements from the literature were first converted to discount rates assuming mid-year cash flows and 30-year equipment lives. Taken as a group, the five studies reported payback periods ranging from 0 through 10 years (see Table E-2 and E-3 below), so initially 11 categories were developed. Next, the zero-risk interest rate for the years in which the five studies were performed were subtracted from the distributions to yield the consumer preference premiums implied by each source. The zero-risk interest rate used was the 10-year Treasury note yield (nominal). Finally, the proportions of consumers at each step in the payback distribution were averaged and adjusted, and the associated consumer preference premiums were weighted by proportions of commercial consumers. Each study was given equal weight because it represented, in general, the utilities' estimates of commercial consumer discount rates, rather than specific statistical studies.

Because each risk-adjusted time preference segment requires computations for all of the relevant technologies and consumes memory storage, the number of risk-adjusted time preference premium categories has direct effects on both model run time and memory requirements. The number of categories was reduced to six, significantly reducing the Commercial Demand Module's runtime as well as its memory requirements. During this category reduction, the input dimensions were extended to have an end-use dimension for the *major* end uses (in other words, explicitly modeled technologies) as well as by model year to allow potentially different values by end use and over time.[34]

Each end use and model year originally had the same risk-adjusted time preference premium distributions and values, and exceptions were made to simulate programs promoting efficient equipment, such as EPA's former Green Lights program and the ENERGY STAR Buildings program. A seventh risk-adjusted time preference premium category was added with a zero premium and a small market share appropriate to model federal buildings hurdle rates as required by FEMP and Executive Order 13123, the *Greening of Government* executive order, and the federal buildings performance standards of EPACT05 and EISA07. The market share assigned to the zero premium is adjusted further for lighting to model the effects of the EISA07 provision that all federal buildings be equipped with energy efficient lighting, including when replacing bulbs in existing fixtures. Additional market share is moved to the zero premium for 2010 through 2013 to account for funding provided in ARRA09 for energy efficiency in public buildings.[35] The adjustments for ARRA09 funding are limited to heating, cooling, ventilation, and lighting based on results of recent surveys conducted by Johnson Controls and by the publishers of *Building Design+Construction*.

Johnson Controls conducted Energy Efficiency Indicator surveys between 2007 and 2011 and received responses from hundreds of members of the International Facility Management Association. The survey also includes responses from thousands of decision makers around the world who are responsible for managing commercial buildings and their energy use. The vast majority of respondents to the surveys are from the United States. The surveys target energy management decision makers to measure the impact of rising energy costs on organizations and their expected payback on energy management improvements. The *Building Design+Construction* survey was conducted in 2008 and targeted architecture, engineering, and construction professionals to determine their "opinions, perceptions, and actions relative to climate change," including whether they have implemented or plan to implement specific technology solutions. The risk-adjusted time preference premium distribution had been adjusted starting in 2008 to align with return on investment categories from these surveys. These sources are supplemented by a 2014 webinar presented by Navigant Consulting, Inc., and an energy efficiency survey by the Institute of Real Estate Management published in 2017.

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[34] Expanding the dimensions of the distributions had virtually no impact on the Commercial Demand Module run time and memory requirements because each modeled technology choice still involved calculations for only six time preference premiums.

[35] Although most stimulus funding authorized in ARRA09 must be obligated by 2011, some funding for new construction is usable through 2013.

Table E-1 presents the premium distribution currently assumed for all model years after 2018.[36] The proportion of consumers in each premium category includes consumers facing all decision types, in other words, new construction, replacement of worn-out equipment, and potential economic retrofit of working equipment. The 1,000% premium simulates floorspace for which existing equipment will never be retrofitted and for which equipment will only be purchased at the lowest capital cost.

Table E-1. Consumer risk-adjusted time preference premium distribution, 2018–2050

Commercial consumers' time preference premium to the risk-free interest rate	Heating	Cooling	Water Heating	Ventilation	Cooking	Lighting	Refrigeration
∞ (represented by 1000%)	26.6%	26.6%	26.4%	25.6%	26.3%	25.6%	25.8%
100%	23.5%	23.6%	23.6%	24.0%	26.2%	24.0%	26.3%
45%	19.6%	19.3%	19.7%	20.0%	21.3%	20.0%	21.5%
25%	18.8%	18.8%	18.7%	18.9%	16.5%	18.9%	16.4%
15%	9.8%	9.7%	9.7%	7.5%	8.4%	7.5%	8.5%
6.50%	1.6%	1.8%	1.7%	1.9%	1.0%	1.9%	1.2%
0.00%	0.2%	0.2%	0.3%	0.2%	0.3%	0.2%	0.3%

Sources: Koomey, Jonathan G., "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," dissertation, University of California at Berkeley, 1990
Adjusted to reflect current energy-efficiency incentives
This dissertation includes a distribution of commercial consumer payback period requirements from a 1986 PEPCO study as summarized in Table E-2. This study was not technology-specific.
Johnson Controls, 2011 Energy Efficiency Indicator: IFMA Partner results, October 2011.
Navigant Consulting, The Leading Edge of New Energy Efficiency and Renewable Energy Technologies Coming to the Market, webinar, September 4, 2014.
DAC and Leidos (formerly SAIC), "Alternative Methodologies for NEMS Building Sector Model Development," draft report, prepared under Contract No. DE-AC01-92EI21946, August 3, 1992, p. 14.
This report lists four commercial consumer payback requirement distributions, summarized in Table E-3. Three of these distributions are from electric utilities, and the fourth is from an EIA market penetration model for rooftop photovoltaic systems. Three of these sources were technology-specific, and one was not.

Table E-2. Commercial customer payback period (PEPCO)

Preferred payback period (years)	Percentage of respondents (N=659)	Implied real internal rate of return (percentage)

[36] For 2010 through 2013, a share of the consumers assigned to the 30%, 17%, and 6.5% premium categories is shifted to the zero-premium category to account for the impact of ARRA09 energy efficiency funding available to public buildings (federal, state, and local).

1	17%	161.8%
2	17%	64.0%
3	18%	39.3%
4	6%	28.3%
More than 4*	10%	19.8%
Don't know **	33%	∞

*Assumes that greater than 4-year payback periods average 5.5 years.

**Assumes that *don't know* implies a zero-year payback period criterion.

Source: Koomey, Jonathan G., "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," dissertation, University of California at Berkeley, 1990, pp. 2–8.

Table E-3. Commercial consumer payback requirement distributions

Payback	Cumulative percentage of consumers with payback requirement			
Period (years)	**Con Ed**	**SCE**	**[Proprietary]**	**EIA**
0	100%	100%	100%	100%
1	100%	100%	70%	100%
2	85%	100%	45%	85%
3	70%	85%	25%	70%
4	45%	70%	12%	45%
5	25%	50%	5%	0%
6	0%	35%	3%	0%
7	0%	20%	1%	0%
8	0%	15%	0%	0%
9	0%	10%	0%	0%
10	0%	5%	0%	0%

Source: DAC and Leidos (formerly Science Applications International Corporation), "Alternative Methodologies for NEMS Building Sector Model Development," draft report, prepared under Contract No. DE-AC01-92EI21946, August 3, 1992, p. 14.

Behavior rule proportions: supporting documentation

Table E-4. Floorspace ownership and occupancy patterns

Building type	Government owned (percentage)	Non-government owner occupied (percentage)	Non-government Non-owner occupied (percentage)
Assembly	21.3%	72.0%	6.7%
Education	77.9%	19.1%	3.0%
Food sales	0.0%	70.4%	29.6%
Food service	20.7%	47.9%	31.4%
Health care	15.1%	79.9%	5.0%
Lodging	6.0%	65.4%	28.5%
Mercantile/service	21.0%	37.4%	41.6%
Office	16.2%	47.5%	36.4%

Warehouse	6.7%	45.5%	47.8%
Other	3.5%	50.3%	46.2%
Total	22.40%	48.06%	29.55%

Source: U.S. Energy Information Administration, *2018 Commercial Buildings Energy Consumption Survey*, Public Use Files, December 2022.

In summary, while the behavior rules are based on the most systematic and recent studies available to EIA, the underlying data are not dispositive of the issues. As a result, historic data calibration, benchmarking, and analysts' expectations continue to contribute to the specific application of the Commercial Demand Module behavior rules.

References

Building Design+Construction, *Green Buildings + Climate Change*, Oak Brook, Illinois, November 2008.

Feldman, S., "Why is it So Hard to Sell 'Savings' as a Reason for Energy Conservation?" *Energy Efficiency: Perspectives on Individual Behavior*, Willett Kempton and Max Neiman eds., American Council for an Energy-Efficient Economy, Washington, DC, 1987.

Institute of Real Estate Management (IREM) of the National Association of Realtors, "Building Performance that Pays: Insights from the First IREM Energy Efficiency Survey," 2017.

Johnson Controls, *2011 Energy Efficiency Indicator: IFMA Partner results*, October 2011.

Komor, P. and R. Katzev, "Behavioral Determinants of Energy Use in Small Commercial Buildings: Implications for Energy Efficiency," *Energy Systems and Policy*, Vol. 12, 1988.

Komor, P., and L. Wiggins, "Predicting Conservation Choice: Beyond the Cost-Minimization Assumption," *Energy*, Vol. 13, No. 8, 1988.

Koomey, J. "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," doctoral dissertation, University of California at Berkeley, 1990.

Lamarre, L., "Lighting the Commercial World," *EPRI Journal*, December 1989.

Lamarre, L., "New Push for Energy Efficiency," *EPRI Journal*, April/May 1990.

Navigant Consulting, Inc., "The Leading Edge of New Energy Efficiency and Renewable Energy Technologies Coming to the Market," webinar, September 4, 2014.

Office of Technology Assessment, *Building Energy Efficiency*, OTS-E-518, U.S. Government Printing Office, Washington, DC, 1992.

U.S. Energy Information Administration, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*, DOE/EIA-0625(95), October 1998.

U.S. Energy Information Administration, *State Energy Data Report 1999, Consumption Estimates*, DOE/EIA-0214(99), May 2001.

U.S. Energy Information Administration, Technical Workshop on Behavioral Economics, November 2013.

Vine, E. and J. Harris, "Implementing Energy Conservation Programs for New Residential and Commercial Buildings," *Energy Systems and Policy*, Vol. 13, No. 2, 1989.