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Commercial Sector Demand Module of the National Energy Modeling System: Model Documentation 2007

April 2007

Office of Integrated Analysis and Forecasting
Energy Information Administration
U.S. Department of Energy
Washington, DC 20585

Update Information

This edition of the *Commercial Sector Demand Module of the National Energy Modeling System-Model Documentation 2007* reflects changes made to the module over the past year for the *Annual Energy Outlook 2007*. These changes include:

- Updating the model inputs to 2003 Commercial Buildings Energy Consumption Survey (CBECS) estimates. Major CBECS changes include:
  - Amount, type, location and age of existing commercial floorspace
  - Technology base year market shares
  - End-use energy use intensities by Census division, building type, and major fuel
  - Commercial module base year now 2003, first year of module execution is 2004
- Updating current and projected lighting, refrigeration and ventilation cost and performance assumptions based on a January 2006 report by Navigant Consulting Inc.
- Updating current and projected cost and performance assumptions for fossil-fired distributed generation/combined heat and power technologies based on a February 2006 report by Discovery Insights LLC
- Incorporating discrete inverter replacements for solar photovoltaic systems in the distributed generation cash flow model
- Incorporating building size classes with appropriate electricity requirements and thermal loads in the distributed generation submodule
- Incorporating additional detailed trend projections for several categories of miscellaneous electricity use based on a September 2006 report by TIAX LLC

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1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach and development of the National Energy Modeling System (NEMS) Commercial Sector Demand Module. The report catalogues and describes the model assumptions, computational methodology, parameter estimation techniques, model source code, and projection results generated through the synthesis and scenario development based on these components.

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 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 Commercial Sector Demand Module is a simulation tool based upon economic and engineering relationships that models commercial sector energy demands at the nine Census division level of detail for eleven distinct categories of commercial buildings. Commercial equipment selections are performed for the major fuels of electricity, natural gas, and distillate fuel, for the major services of 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 demand for the minor fuels of residual oil, liquefied petroleum gas, steam coal, motor gasoline, and kerosene, the renewable fuel sources of wood, municipal solid waste, and solar energy, and the minor services of office equipment (with a separate breakout of personal computers) and "other" in less detail than the major fuels and services. Commercial decisions regarding the use of distributed generation and combined heat and power (CHP) technologies are performed using an endogenous positive 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 Module generates projections of commercial sector energy demand. The model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact commercial sector energy demand.

Model Archival Citation

This documentation refers to the NEMS Commercial Sector Demand Module as archived for the *Annual Energy Outlook 2007 (AEO2007).*

Organization of this Report

Chapter 2 of this report discusses the purpose of the model, detailing its objectives, primary input and output quantities, and the relationship of the Commercial Module to the other modules of the NEMS system. Chapter 3 of the report describes the rationale behind the model design, providing insights into further assumptions utilized 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 Appendices 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 NEMS system and the model evaluation process. A table referencing the equation(s) 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. A discussion of the sensitivity of the model outputs to variations in fuel prices is presented in "Price Responsiveness in the *AEO2003* NEMS Residential and Commercial Buildings Sector Models," available at EIA's web site.[1] Other analyses discussing alternate assumptions, sensitivities, and uncertainties in projections developed using the NEMS Commercial Demand Module are available at EIA's web site.[2]

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[1]See http://www.eia.doe.gov/oiaf/analysispaper/elasticity/index.html.

[2]See http://www.eia.doe.gov/oiaf/demand.html.

2. Model Purpose

Model Objectives

The NEMS Commercial Sector Module serves three objectives. First, it develops projections of commercial sector energy demand, currently through 2030[3], as a component of the NEMS integrated projection system. The resulting projections are incorporated into the *Annual Energy Outlook*, published annually by the Energy Information Administration of the U.S. Department of Energy (DOE). 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 the NEMS system, it provides inputs to the Electricity Market Module (EMM), Coal Market Module (CMM), Natural Gas Transmission and Distribution Module (NGTDM), and Petroleum Market Module (PMM) of NEMS, contributing to the calculation of the overall energy supply and demand balance of the U.S. energy market.

The Commercial Sector Demand Module projects commercial 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 oil by the equipment chosen.[4] These projections are based on energy prices and macroeconomic variables from the NEMS system, combined with external data sources.

Projected commercial sector fuel demands generated by the Commercial Sector Demand Module are used by the NEMS system in the calculation of 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 sectoral 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 Commercial Sector Module 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. Both the input file structure and the model source code have been specially developed to facilitate "what if" analyses of energy markets, technology characterizations, market initiatives, environmental concerns, and regulatory policies such as demand-side

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[3]The base year for the Commercial Module is currently 2003, corresponding to the last available energy consumption survey of commercial buildings. Dynamic projections dependent on feedback from the rest of NEMS are made for the years 2004 through 2030, whereas consumption results reported for 1990 through 2003 are historical.

[4]The End-Use Consumption Module accounts for commercial sector consumption of five minor fuels. These fuels do not account for enough commercial sector consumption to justify modeling at the same level of detail as the three major fuels (distillate fuel oil, natural gas, and electricity). The five minor fuels are residual fuel oil, liquefied petroleum gas (LPG), coal, motor gasoline and kerosene.

management (DSM) programs. Examples of specific policy analyses that can be addressed using this model include assessing the potential impacts of:

- New end-use technologies (for example, compact fluorescent light bulbs or ground source heat pumps)
- New energy supply technologies (for example, solar thermal heating or fuel cells)
- Federal, state and local government policies, including:
- changes in fuel prices due to 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 programs[5]

Model Input and Output

Inputs

The primary inputs to the Commercial Sector Demand Module include fuel prices, commercial building floorspace growth, interest rates, and technology characteristics. The technology characteristics used by the model for end-use equipment include first and last year of availability for each system, equipment market share in 2003, installed capital cost per unit of service demand, operating and maintenance cost per unit of service demand, equipment efficiency, removal/disposal cost, building restrictions, service provided, fuel used, expected equipment lifetime, and cost trend parameters.[6] The technology characteristics used by the model for distributed generation technologies are included in the summary of major inputs that follows. Additional detail on model inputs is provided in Appendix A. The major inputs by model component are summarized as follows:

Inputs to Floorspace Component

- Existing distribution of commercial building floorspace stock in 2003
- Median construction year of existing commercial buildings by type, vintage, and location

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[5]Recent examples of the use of the NEMS Commercial Sector Module in policy analyses can be found on EIA's web site at http://www.eia.doe.gov/oiaf/demand/html.

[6]Technology characteristics for heating, cooling, and water heating equipment are based on Navigant Consulting, Inc., *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies*, Reference No. 117934, prepared for U.S. Department of Energy, Energy Information Administration, September 2004.

- Building survival parameters
- Commercial building floorspace growth

Inputs to Service Demand Component

- Energy Use Intensities (EUI) in 2003
- Commercial technology characterizations
  - market share of equipment existing in 2003
  - equipment efficiency
  - building restrictions
  - service provided
  - fuel used
- Building shell efficiency indices for new floorspace
- Building shell efficiency improvement through 2030 for existing and new floorspace
- Market penetration projections for office equipment and "other" end-use category
- Steam EUIs to provide District Energy Services in 2003
- Efficiencies of boilers providing District Energy Services in 2003
- Fuel shares of District Energy Service steam production in 2003
- Short-run price elasticities of service demand
- Historical and average heating and cooling degree days
- Differences in serviced floorspace proportions between existing and new floorspace

Inputs to Distributed Generation/CHP Component

- Distributed generation 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 systems)
  - inverter replacement interval (solar photovoltaic systems)
  - equipment life

- tax life and depreciation method
- available federal tax credits
- generation and thermal heat recovery efficiency
- annual operating hours
- penetration function parameters
- learning function parameters

- Financing parameters
- Building-size category characteristics within building type
  - average annual electricity use
  - average building size in square feet
  - share of floorspace
- Program-driven market penetration projections for distributed generation technologies
- Historical CHP generation of electricity data

Inputs to Technology Choice Component

- 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 bond 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 2003
  - installed capital cost per unit of service demand
  - operating and maintenance cost per unit of service demand
  - equipment efficiency
  - removal/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 Component

- Short Term Energy Outlook (STEO) consumption projections
- Annual Energy Review (AER) consumption information
- State Energy Data System (SEDS) consumption information
- Components of SEDS data attributable to other sectors
- Minor fuel elasticity parameters

Outputs

The primary output of the Commercial Sector 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:

- construction of new commercial floorspace by building type and Census division
- surviving commercial floorspace by building type, year of construction, and Census division
- equipment market shares by technology, end-use, fuel, building type, and Census division
- distributed generation and CHP generation of electricity
- quantities of fuel consumed for distributed generation 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 are required to exchange information with the supply modules at the nine Census division level of detail spatially, and average annual level temporally. Information exchanged between the Commercial Demand Module and the EMM is also required at the end-use service level of detail. The input data available from the Commercial Buildings Energy Consumption Survey (CBECS) performed by EIA (which forms the basis for the

Commercial Sector Demand Module) and other sources are designed to be statistically significant at various levels, some of which are above the nine Census division level. Commercial Sector Demand Module variables are resolved at a relatively fine level of detail in order to capture heterogeneous effects that manifest themselves at a high level of aggregation, yet which originate from variations at a disaggregate level. The primary dimensions across which key variables vary are set forth in **Table 1**, which also shows the notation generally used to represent the dimensions in this report:

Table 1. Primary Dimensions Spanned by Commercial Module Variables

Dimension:	**Census Division**	**Building Type**	**End-Use Service**		**Fuel**	
Subscript:	**r**	**b**	**s**		**f**	
Index Value				**Category**		**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 Oil	
4	West North Central	Food Service	Ventilation		Residual Oil	Minor
5	South Atlantic	Health Care	Cooking		Liquid Petroleum Gas (LPG)	
6	East South Central	Lodging	Lighting		Steam Coal	
7	West South Central	Office - Large (>50,000 ft2)	Refrigeration		Motor Gasoline	
8	Mountain	Office - Small (≤50,000 ft2)	Office Equipment - PCs	Minor	Kerosene	
9	Pacific	Mercantile & Service	Office Equipment - Other than PCs		Wood	Renewables
10		Warehouse	Other		Municipal Solid Waste (MSW)	
11	U.S. Total	Other			Hydro	
12					Waste Heat	Other
13					Other Gaseous Fuels (OGF)	

In addition to the dimensions shown in **Table 1**, over which most Commercial Module variables vary, there are several other domains of variation considered by certain classes of variables. These domains are represented through the use of the subscripts listed alphabetically in **Table 2**. The subscripts are described briefly below, as needed, with additional detail provided in Chapter 4 of this report.

Table 2. Subscripts for Commercial Module Variables

Subscript	Potential Range	Description
mc	1 through 10	Miscellaneous electricity use category. Category index for specific category of electricity use within “Other” end-use services.
ntek	1 through 10	Technology number. Technology type for distributed generation/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 11	Technology vintage. Specific vintage or model within a technology class.
y	1 through 41	Time dimension for Commercial Module variables. A value of 1 corresponds to the year 1990 and a value of 41 corresponds to 2030.

Consumer risk-adjusted time preference premium segments are represented by the subscript p, and represent the percent increment to the risk-free interest rate in the current year, used to segment commercial consumer behavior patterns. The model currently uses a discrete distribution of seven (7) 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 make up the consumer hurdle (or implicit discount) rates utilized in equipment purchase decisions. Additional detail is provided in Chapter 4 of this report.

Equipment defined in the Commercial Sector Technology Characterization Database, KTECH, is represented through the use of 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 models (v) for competition in the Technology Choice Submodule. The current Technology Choice Submodule allows for a maximum of 11 vintages for each piece of representative equipment. An example of two different vintages for the same technology class would be: 1) an electric resistance water heater with an energy factor[7] of 0.80, available in 1995 and 2) an electric resistance water heater with an energy factor of 0.91, available in 2000 and beyond. The later vintage represents an updated model in this example.

[7]An efficiency measure defined in terms of delivered Btu divided by input Btu.

The Major Service end-uses listed in **Table 1** are modeled in the Technology Choice Submodule described in Chapter 4 of this report. Minor end-uses are projected using equipment efficiency and market penetration trends. Projected energy demands for the major fuels listed in Table 1 take into account the price elasticity of service demand and efficiency rebound effects. Minor fuel demands are projected using a moving average of previous years' fuel use, adjusted to account for sector growth and price elasticity. The modeling methodology for projecting minor end-uses and fuel demands and the considerations just mentioned are described in more detail in Chapter 4 of this report.

Relationship of the Commercial Module to Other NEMS Modules

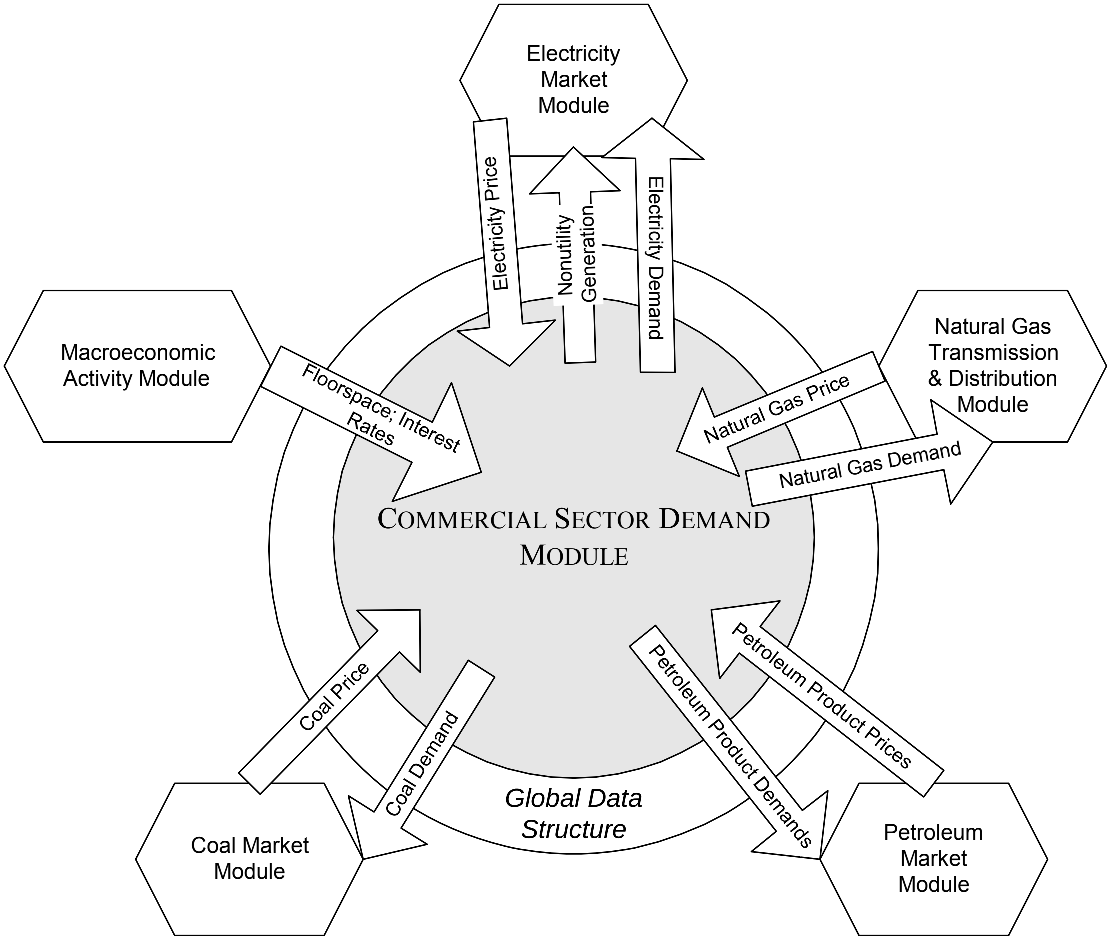
The Commercial Module receives input data from the Macroeconomic Activity Module (MAM) and the energy supply modules. The commercial floorspace projections and ten-year Treasury bond interest rates generated by MAM are used to calculate annual new additions to floorspace and annualized technology capital 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 NGTDM, and the petroleum prices from the PMM are primary drivers for the technology cost comparison, projections of commercial sector distributed generation, and price foresight scenarios. The Commercial Module provides energy consumption projections by Census division and fuel to the supply modules listed above, from which supply resources and capacity plans are developed.

This relationship of the Commercial Module to other components of NEMS is depicted schematically in **Figure 1**. As shown, all exchanges of information between the modules take place through the NEMS Global Data Structure. Not shown is the NEMS Integrating Module, which directs the activation of the sectoral modules, thus controlling the sequence and iteration of modeled considerations at the sector level. For a more detailed description of the approach taken by the Integrating Module within the NEMS general equilibrium solution to interactions between the U.S. energy markets and the economy, the reader is referred to the Integrating Module Documentation Report[8] and the NEMS Overview[9].

[8]Energy Information Administration, *NEMS Integrating Module Documentation Report 2007*, DOE/EIA-M057 (2007) (Washington, DC, April 2007).

[9]Energy Information Administration, *National Energy Modeling System: An Overview 2003*, DOE/EIA-0581(2003) (Washington, DC, March 2003).

Figure 1. Commercial Sector Demand Module's Relationship to Other NEMS Modules



3. Model Rationale

Theoretical Approach

The Commercial Module utilizes a simulation approach to project energy demands in commercial buildings. The specific approach of the Commercial Module involves explicit economic and engineering-based analysis of the building energy end uses of space heating, space cooling, water heating, ventilation, cooking, lighting, refrigeration, office equipment, and "other" energy-consuming equipment. These end-uses are modeled for eleven distinct categories of commercial buildings at the Census division level of detail.

The model is a sequentially structured system of algorithms, with succeeding computations utilizing 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.

In the default mode, the Commercial Module 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 model is capable of accommodating the alternate scenarios of adaptive foresight and perfect foresight within the NEMS system.

A key assumption that is integrated into the technology characterization database that forms the basis of the technology selection process is the incorporation of the equipment efficiency standards described in the Energy Policy Act of 1992 (EPACT92) and in the Energy Policy Act of 2005 (EPACT05).[10] In addition, residential-type equipment used in commercial buildings, such as room air conditioners, are subject to provisions contained in the National Appliance Energy Conservation Act of 1987 (NAECA). This is modeled in the database by ensuring that all available choices for equipment covered by these laws meet the required efficiency levels. As the Department of Energy continues to promulgate and update efficiency standards under EPACT92, EPACT05, and NAECA, changes are modeled by the elimination of noncompliant equipment choices and introduction of compliant equipment choices by the year the new standards take effect. Through this database, the Commercial Module is able to model equipment efficiency legislation as it continues to evolve.

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[10] For a description of Commercial Module handling of legislative provisions that affect commercial sector energy consumption, including EPACT05 standards and tax credit provisions, see the Commercial Demand Module section of *Assumptions to the Annual Energy Outlook 2007* available at http://www.eia.doe.gov/oiaf/aeo/index.html.

Fundamental Assumptions

Floorspace Submodule

When the model runs begin, the existing stock, geographic distribution, building usage distribution, and vintaging of floorspace is assumed to be the same as published in the 2003 CBECS[11].

New additions to the floorspace stock through the projection period are assumed to conform to building standards as described in End-Use Energy Consumption Estimates for U.S. Commercial Buildings, 1989, Pacific Northwest Laboratory, PNL-8946, November 1993, with assumptions updated to reflect building standards in effect through 1999.[12]

Service Demand Submodule

The average efficiency of the existing stock of equipment for each service is calculated to produce the 2003 CBECS energy consumption when the Energy Use Intensities (EUIs) derived from the 2003 CBECS data are applied.

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

Service Demand Intensity (SDI) is assumed constant over the projection period (for a given service, building type and vintage, and Census division). The primary components of the SDI calculation, EUIs and average equipment efficiencies, are assumed to change over time in a manner that preserves the SDI.

The market for the largest major services is assumed to be 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. The proportion of consumers that follows each behavioral rule is developed based upon quantitative assessment and specific assumptions that are referenced in Appendix A to this report.

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[11]Energy Information Administration, 2003 CBECS Public Use Files as of August 2006. See web site www.eia.doe.gov/emeu/cbecs/contents.html for current CBECS Public Use Files.

[12]Regional building shell efficiency parameters that reflect current building codes and construction practices were developed from a 1998 Arthur D. Little study. Data from the 1999 CBECS were used to adjust the parameters to account for new construction between 1990 and 1999. The parameters will be adjusted to account for new construction between 2000 and 2003 for the *Annual Energy Outlook 2008*. A more detailed description of the building shell efficiency parameters is provided in Appendix A.

The technology selection is performed using a discrete distribution of consumer risk-adjusted time preference premiums. These premiums are developed based on analysis of survey results and additional literature, employing specific assumptions about consumer behavior in order to quantify these concepts for inclusion in the model. Documentation of these assumptions is referenced in Appendix A to this report.

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.

Energy efficiency and continuing market penetration for minor services (office equipment and "other" services) increases over the projection period based on published sources that are further referenced in Appendix A to this report. Office equipment is assumed to consume only electricity, and fuel switching is not addressed.

4. Model Structure

Structural Overview

The commercial sector encompasses business establishments that are not engaged in industrial or transportation activities. Commercial sector energy is consumed primarily within buildings.[13] Energy consumed in commercial buildings is the sum of energy required to provide specific energy services using selected technologies. The model structure carries out a sequence of six basic steps for each projection year. The first step is to project commercial sector floorspace. The second step is to project the energy services (e.g., space heating, lighting, etc.) required by that building space. The third step is to project electricity generation and energy services to be met by distributed generation technologies. The fourth step is to select specific end-use technologies (e.g., gas furnaces, fluorescent lights, etc.) to meet the demand for energy services. The fifth step is to determine the amount of energy consumed by the equipment chosen to meet the demand for energy services. The last step is to benchmark consumption results to published historical data. New construction, surviving floorspace, and equipment choices projected for previous time periods largely determine the floorspace and equipment in place in future time periods. 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 Commercial Sector Demand Module, 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 components are given.

Commercial Building Floorspace Projection

Commercial sector energy consumption patterns depend upon numerous factors, including the composition of commercial building and equipment stocks, regional climate, and building construction variations. The NEMS Commercial Sector Demand Module first develops projections of commercial floorspace construction and retirement by type of building and Census division. Floorspace is projected for the following 11 building types:

- Assembly
- Education
- Food Sales
- Food Services
- Health Care
- Lodging
- Office - large
- Office – small
- Mercantile and Service
- Warehouse
- Other

[13]There is a small amount of commercial energy consumption (from uses such as street lights and municipal water services) that is not attributed to buildings. This is discussed in the End-Use Consumption section.

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 the services that energy provides.[14] This demand for delivered forms of energy is measured in units of Btu out by the Commercial Module, to distinguish it from the consumption of fuel, measured in Btu in, necessary to produce the useful services. The following ten services, based in part on the level of detail available from published survey work discussed further in this report, are tracked:

- Space Heating
- Water Heating
- Refrigeration
- Space Cooling
- Lighting
- Office Equipment - Personal Computers
- Ventilation
- Cooking
- Office Equipment - Other than PCs
- Other

The energy intensity of usage, measured in Btu/sq ft, 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.[15] For electricity, the model uses a weighted-average price for each end-use service and Census division. For each of the other 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 efficiencies and building shell efficiencies on the marginal cost of the service to the consumer, resulting in a “takeback effect” or “rebound effect” modification of the pure price elasticity.

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

[15]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 is necessary because the fuel shares of provided services are not determined until after selection of the equipment mix by the Technology Choice Submodule.

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. Historical data are used to derive CHP electricity generation through 2005. In addition, program-driven installation of solar photovoltaic systems and fuel cells are input based on information from DOE and DOD, referenced in Appendix A. After 2005, distributed and CHP electricity generation projections are developed based on economic returns. The module uses a detailed cash-flow approach to estimate the number of years required to achieve a cumulative positive cash flow. Penetration of distributed and CHP generation technologies is a function of how quickly an investment in a technology recoups its cost.

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 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).

Each type of demand is referred to 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.[16] The NEMS Commercial Module is coded to allow the use of several possible assumptions about consumer behavior. The consumer behavior assumptions are:

- 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 upon minimum life-cycle costs.

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[16]See Jon Koomey, "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," Dissertation, University of California at Berkeley, April 1990; and U.S. Congress, Office of Technology Assessment, Building Energy Efficiency, OTA-E-518, Washington DC: U.S. Government Printing Office, May 1992, pp. 73-85.

These behavior rules are designed to represent empirically the range of economic factors that influence the consumer's decision. 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 vary by building type, the end-use service under consideration, and decision type, for the three decision types of new construction, replacement, or retrofit.[17]

The model is designed to choose among a discrete set of technologies exogenously characterized by commercial availability, capital cost, operating and maintenance (O&M) cost, removal/disposal cost, efficiency, and equipment life. The menu of equipment depends on technological innovation, market development and policy intervention. The design is capable of accommodating 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 of time.

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. An example of this calculation is shown in **Table 3**. If 100 million Btu (MMBtu) 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 a given fuel (**Table 3**, Column 3); divide service demand (Column 3) by the average efficiency (Column 4) to derive fuel consumption by fuel type.

Table 3. Energy Consumption Calculation Example

Service Demand (100 MMBtu 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

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

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 (e.g., radio transformer 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 Commercial Sector Demand Module. The flow proceeds sequentially, with each succeeding Submodule utilizing as inputs the outputs of preceding Submodules. In other words, the outputs of the Floorspace Submodule are used as inputs to the Service Demand Submodule, the outputs of the Service Demand Submodule are used as inputs to the Technology Choice Submodule, and the outputs of the Technology Choice Submodule are used as inputs to the End-Use Consumption Submodule. The basic processing flow used by the Commercial Module to generate its projection of fuel demands consists of six steps:

1. A projection of commercial building floorspace is generated based upon input from the Macroeconomic Module and results from previous years. (COMFloorspace Submodule).

2. Demands for services are calculated for that distribution of floorspace (COMServiceDemand Submodule).

3. Distributed generation and CHP technologies are chosen to meet electricity demand in place of purchased electricity where economical (CDistGen).

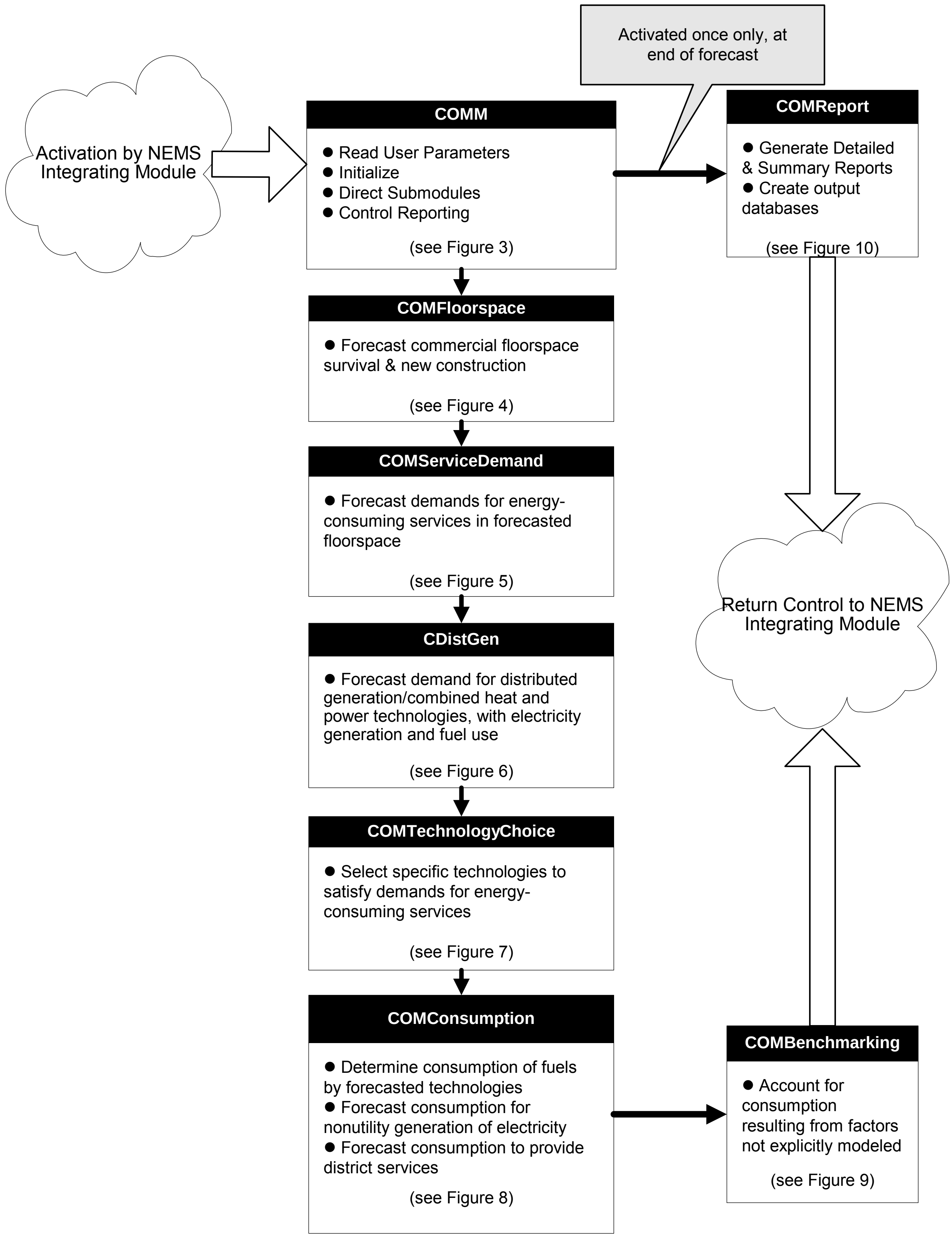
4. Equipment is chosen to satisfy the demands for services (COMTechnologyChoice Submodule).

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 the 1990 through 2003 State Energy Data System (SEDS) historical data, 2004-2005 historical estimates from the *Annual Energy Review 2005*[18] (AER), and optionally the 2006-2007 projections of the *Short Term Energy Outlook* (STEO) (COMBenchmarking Submodule).

[18]Energy Information Administration, *Annual Energy Review 2005*, DOE/EIA-0384(2005) (Washington, DC, July 2006).

Figure 2. Commercial Module Structure & Fundamental Process Flow



The Commercial Module is activated one or more times during each year of the projection period by the NEMS Integrating Module. On each occurrence of module activation, the processing flow follows the outline shown in **Figure 2**. Details of the processing flow within each of the Commercial Module's submodules, together with the input data sources accessed by each, are shown in **Figures 3** through **9**, and 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 component of the Commercial Module, COMM. This is the component that 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 directs the generation of printed reports and output databases to the extent specified by the user.

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

Figure 5 illustrates the processing flow within the Service Demand Component of the model, 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 (2003) Energy Use Intensities (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 due to equipment failure, and surviving floorspace with currently functioning equipment.

Figure 6 illustrates the processing flow within the Distributed Generation and CHP Component of the model, CDistGen. Technology specific inputs and financing parameters are required by the Distributed Generation and CHP Submodule, 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 distributed generation 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 Component, COMTechnologyChoice. The service demands produced by the Service Demand Submodule, combined with equipment-specific inputs, consumer behavior characterization and risk-adjusted time preference segmentation information specific to the Commercial Module, and NEMS system outputs including Treasury Bill rates from the MAM and fuel prices from the EMM, NGTDM, and PMM, are required by the Technology Choice Submodule. 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 retrofitting of economically obsolete equipment. Also calculated are the corresponding fuel shares and average equipment efficiencies by end-use service and other dimensions.

Figure 8 illustrates the processing flow within the Consumption Component, 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 Component to produce the projection of major fuel consumption by building type, Census division, and end-use. Several additional considerations are incorporated 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. Demands for the five minor fuels are also projected by this component using the floorspace projections together with fuel prices and a moving average of previous years' consumption.

Figure 9 illustrates the Benchmarking Component of the fuel consumption projection, COMBenchmarking. Data input from the State Energy Data System (SEDS), and, at the user's option, fuel consumption projections produced for the Short Term Energy Outlook (STEO), are compared with the basic Commercial Module 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 Commercial Module. The difference between the basic Commercial Module 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. The notation that SEDS data are available after data provided by the NEMS global data system reflects the fact that AER data are available for at least an additional year beyond the latest published SEDS results, and are used in the same manner as published SEDS data. If desired, the calculated non-building consumption is evolved in one of several methods chosen by the user and added to the basic Commercial Module projection.

A final reporting subroutine, COMReport, generates detailed documentation on the Final Control and Reporting Loop of the last projection year. Numerous subcategories and additional considerations are handled by the model for each of the broad process categories given above. These 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.

Figure 3. COMM Calculation Process Flow

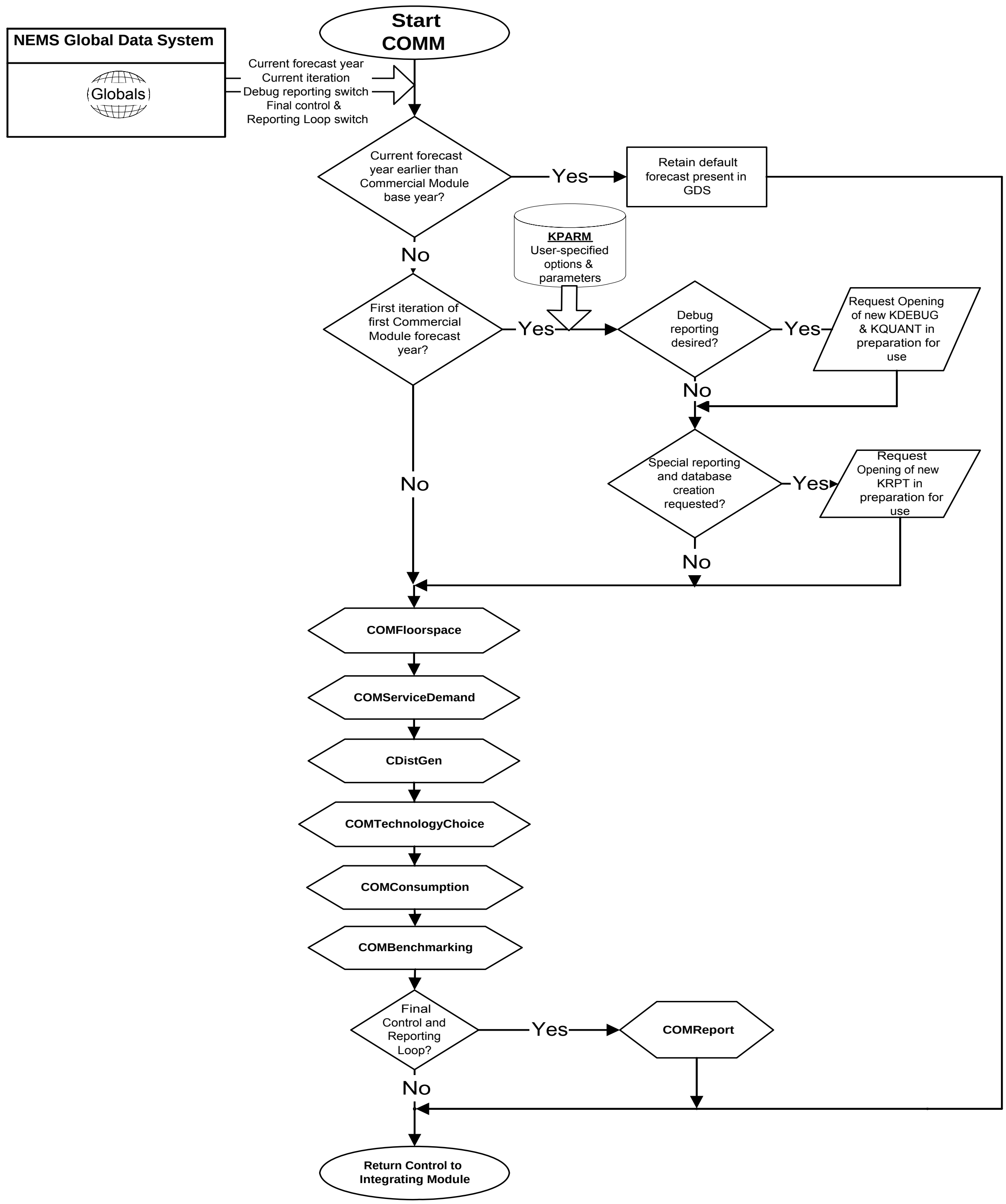


Figure 4. COMFloorspace Calculation Process Flow

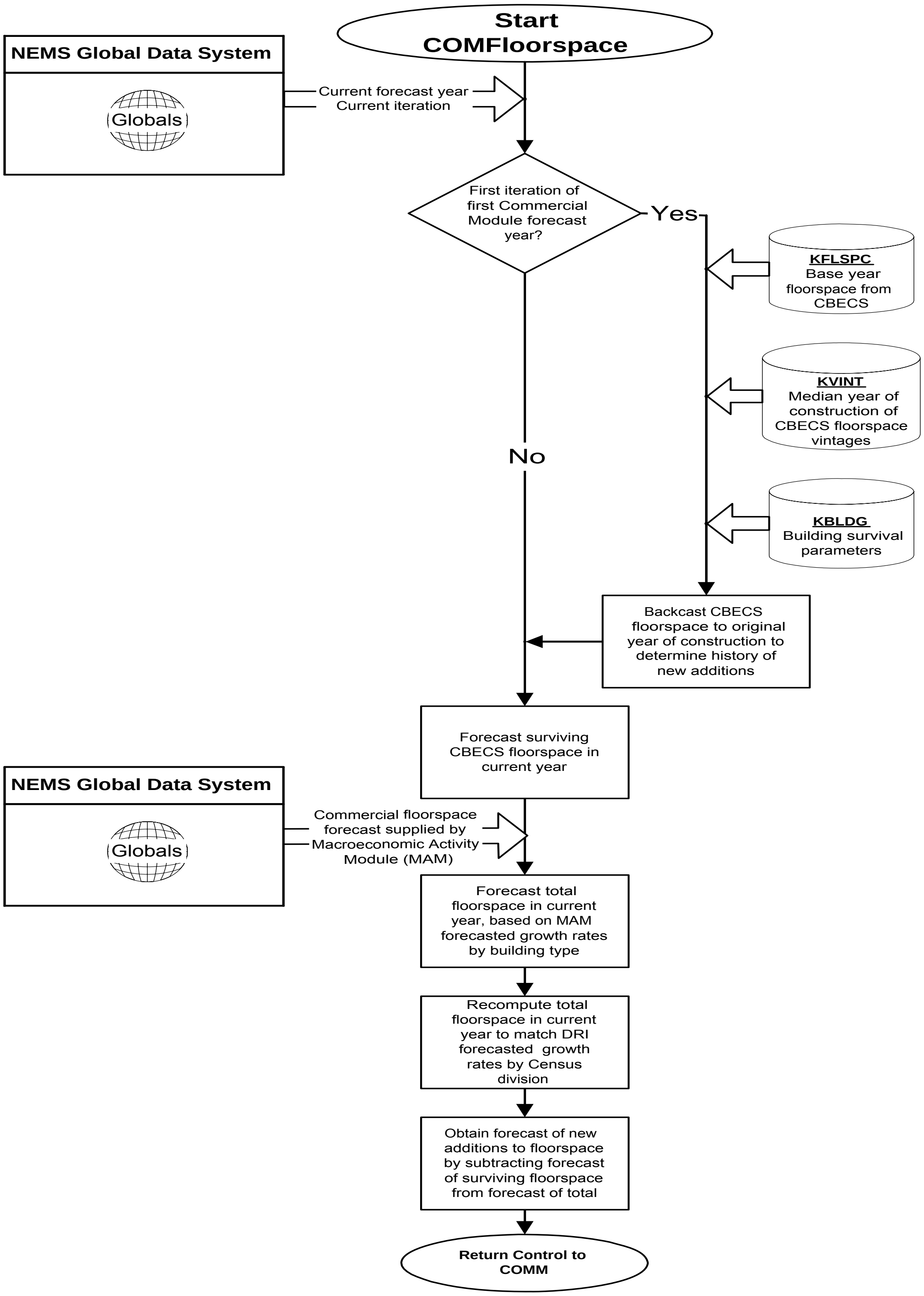


Figure 5. COMServiceDemand Calculation Process Flow

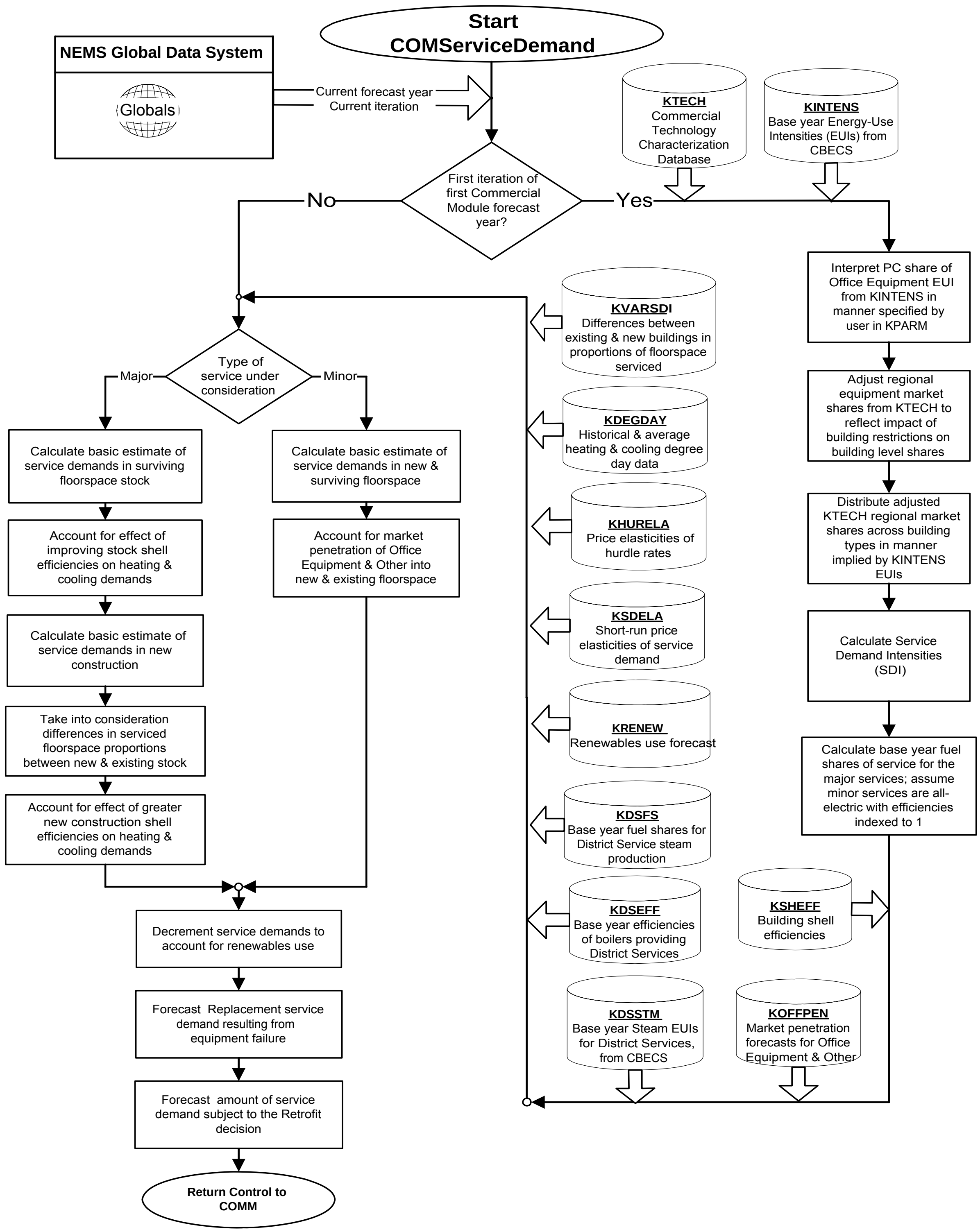


Figure 6. CDistGen Calculation Process Flow

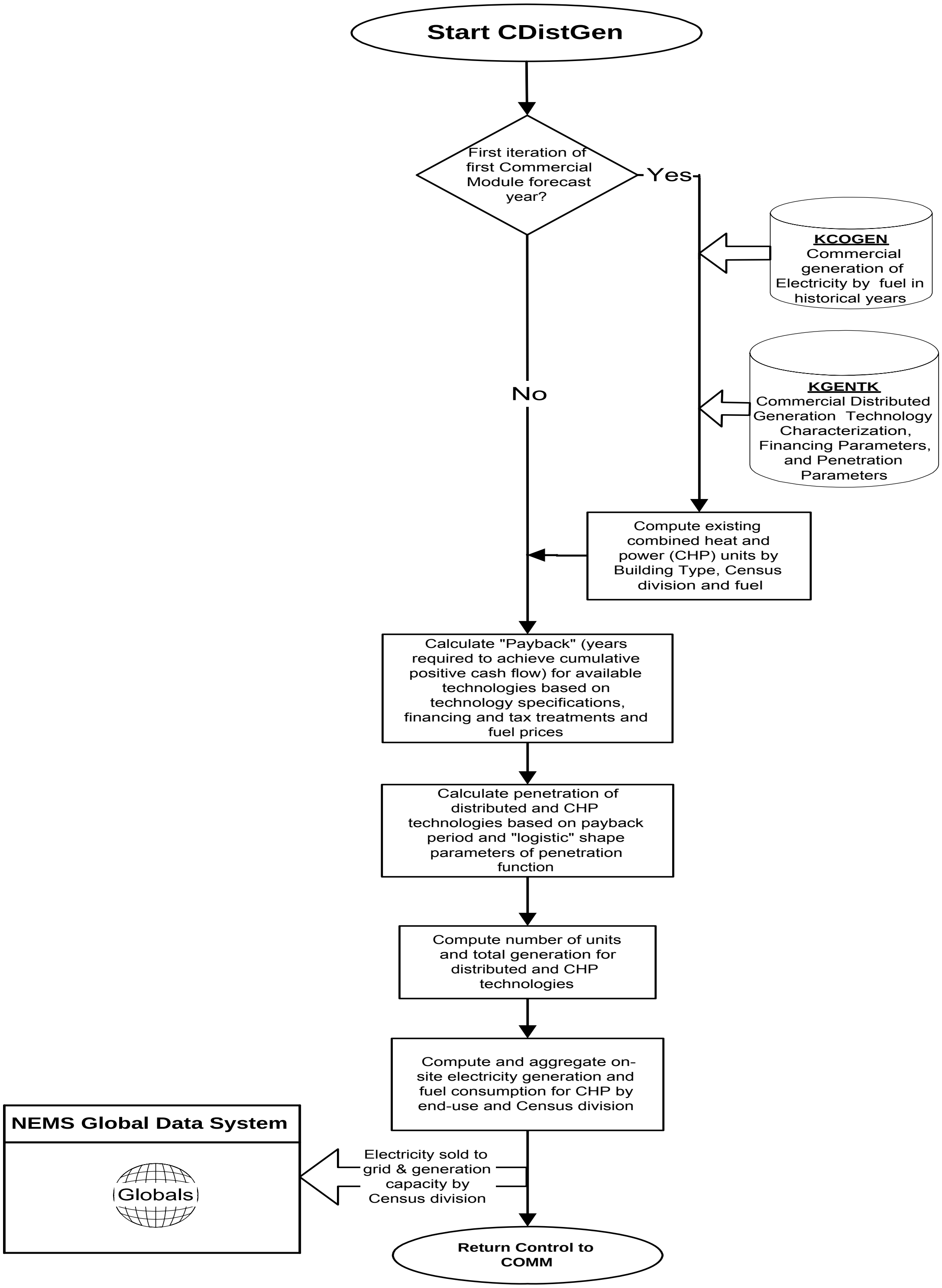


Figure 7. COMTechnologyChoice Calculation Process Flow

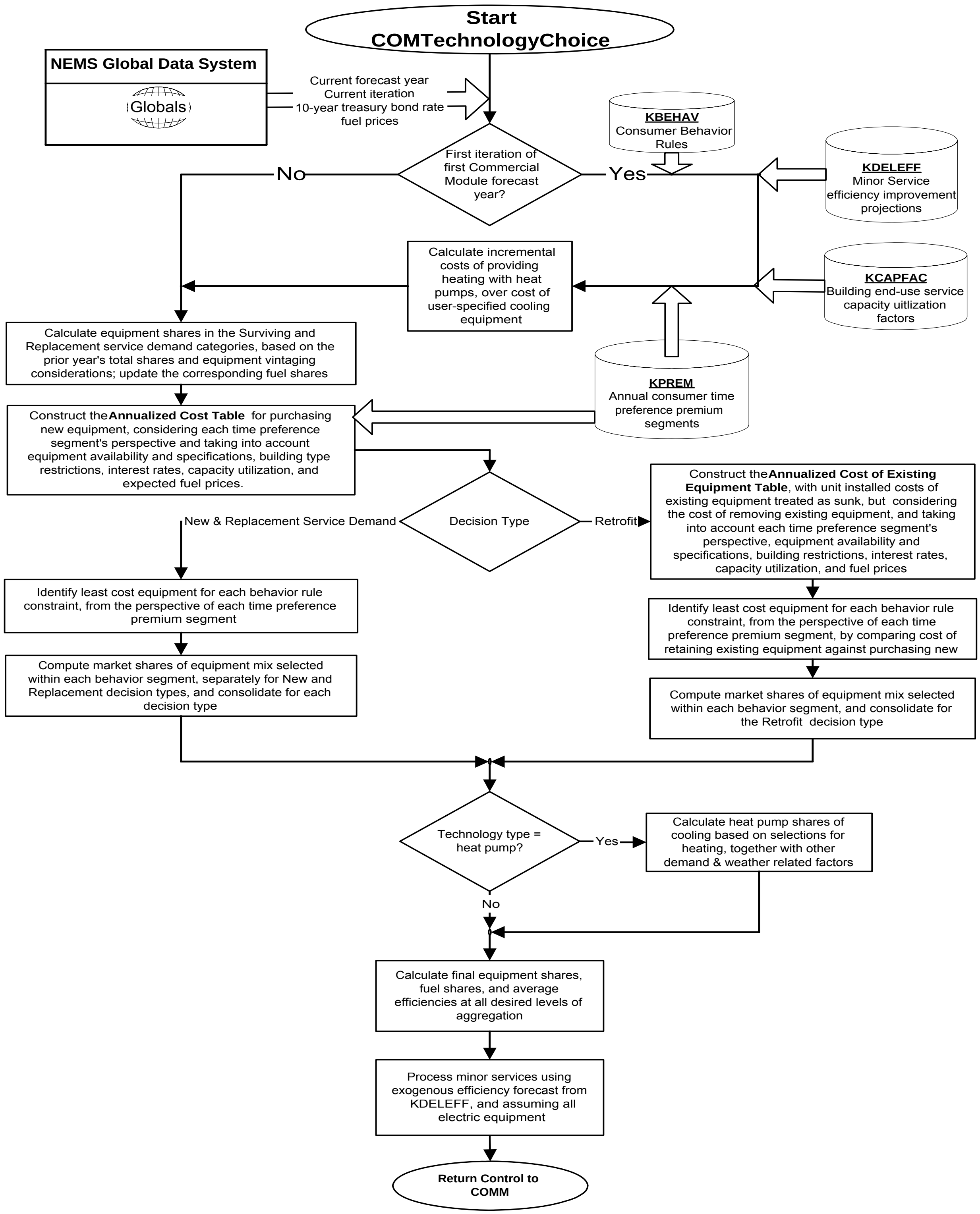


Figure 8. COMConsumption Calculation Process Flow

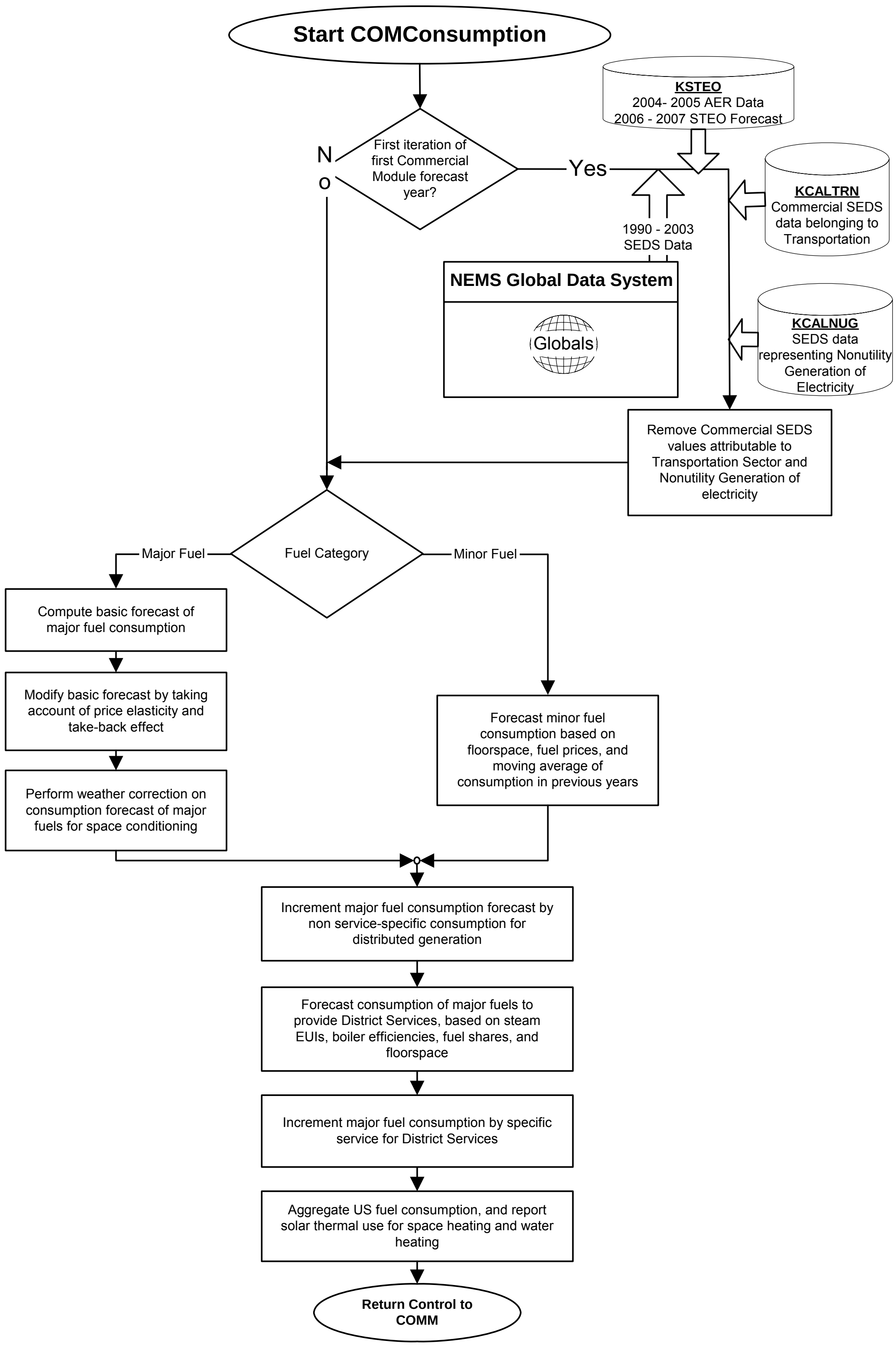
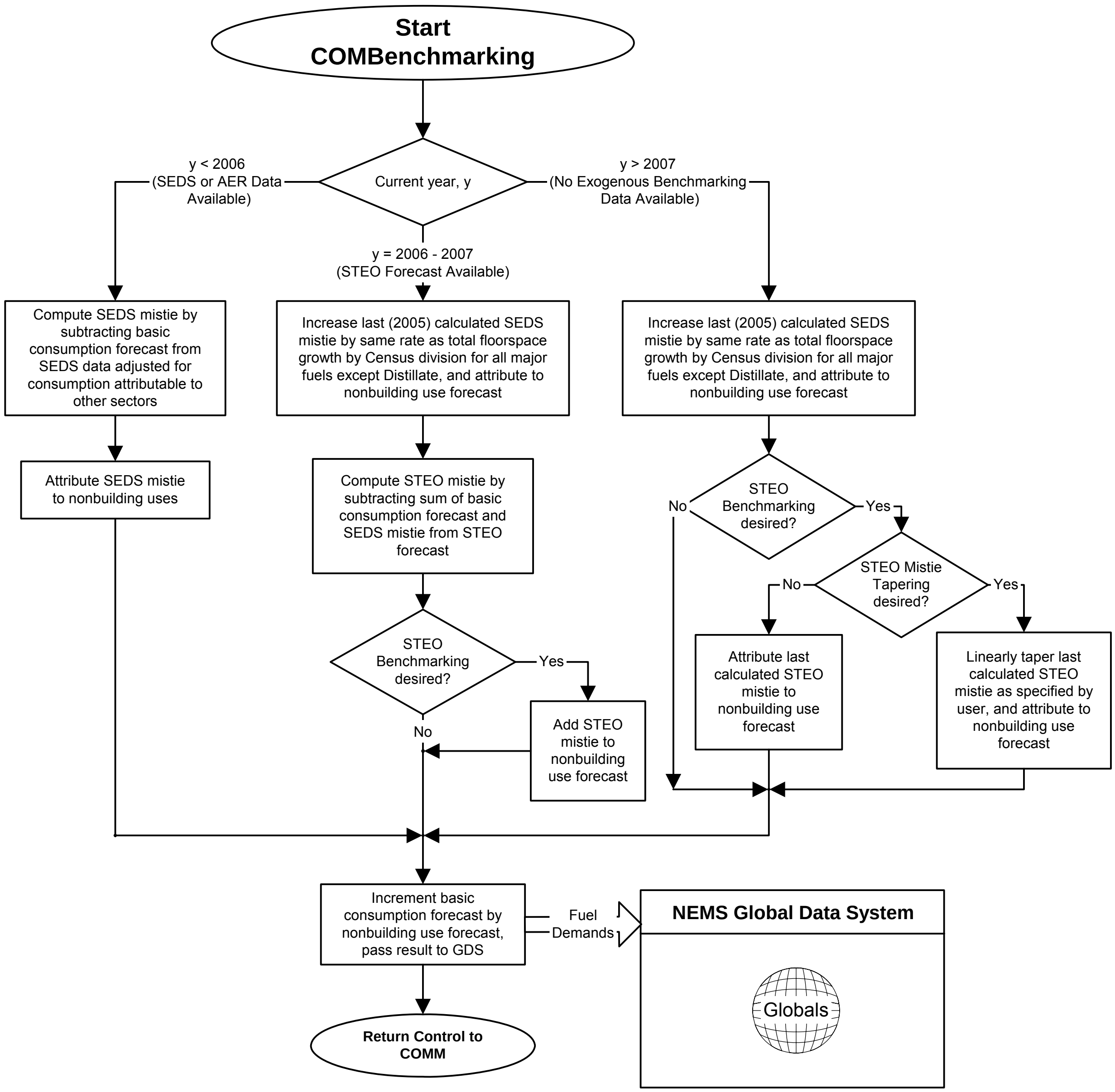


Figure 9. COMBenchmarking Calculation Process Flow



Key Computations and Equations

This section provides detailed solution algorithms arranged by sequential submodule as executed in the NEMS Commercial Sector Demand Module. 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 utilizes the Census division level building-specific total floorspace projection from the MAM as its primary driver. Many of the parameter estimates used in the Commercial Module, including base year (2003) commercial sector floorspace, are developed from the 2003 CBECS database. Projected total commercial floorspace is provided by the MAM through the MC_COMMFLSP member of the NEMS Global Data Structure (GDS).[19] Commercial floorspace from the MAM is specified by the 13 building categories of the database of historical floorspace estimates developed by F.W. Dodge of McGraw-Hill, Inc. and projected at the Census division level based on population, economic drivers (per capita income and interest rates), and historical time trends. To distinguish the Commercial Module floorspace projection ultimately produced within the Commercial Module from that provided by the MAM, the latter is referred to as the MAM floorspace projection in this report.

The Floorspace Submodule first backcasts the 2003 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 is calculated in a way that causes total floorspace to grow at the rate indicated by the MAM projection. In the event that 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 upon 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 Commercial Module, and is given by Equation B-1 in appendix B. This survival function, also referred to as the retirement function, is of the form:

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

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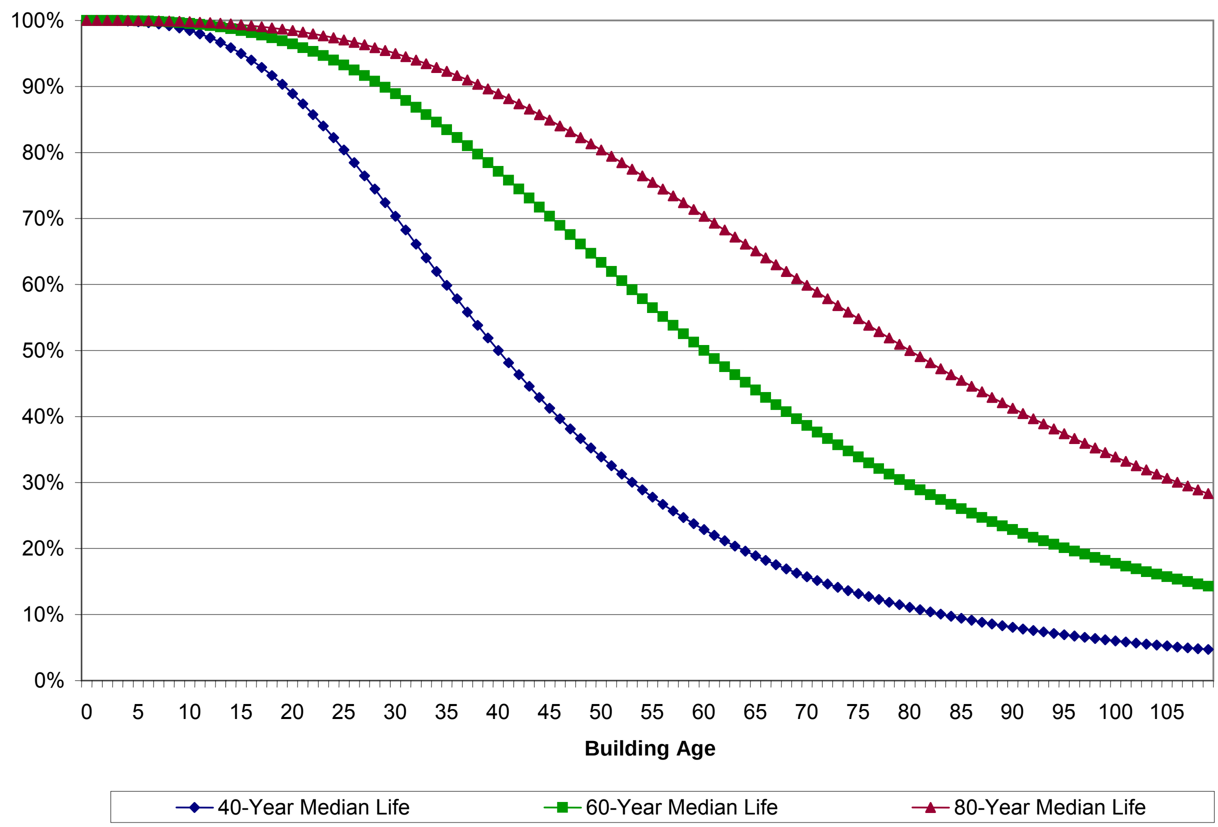
[19]For the methodology used to develop the MAM floorspace projection, please see Energy Information Administration, *Model Documentation Report: Macroeconomic Activity Module (MAM) of the National Energy Modeling System*, DOE/EIA-M065 (2007) (Washington, DC, January 2007).

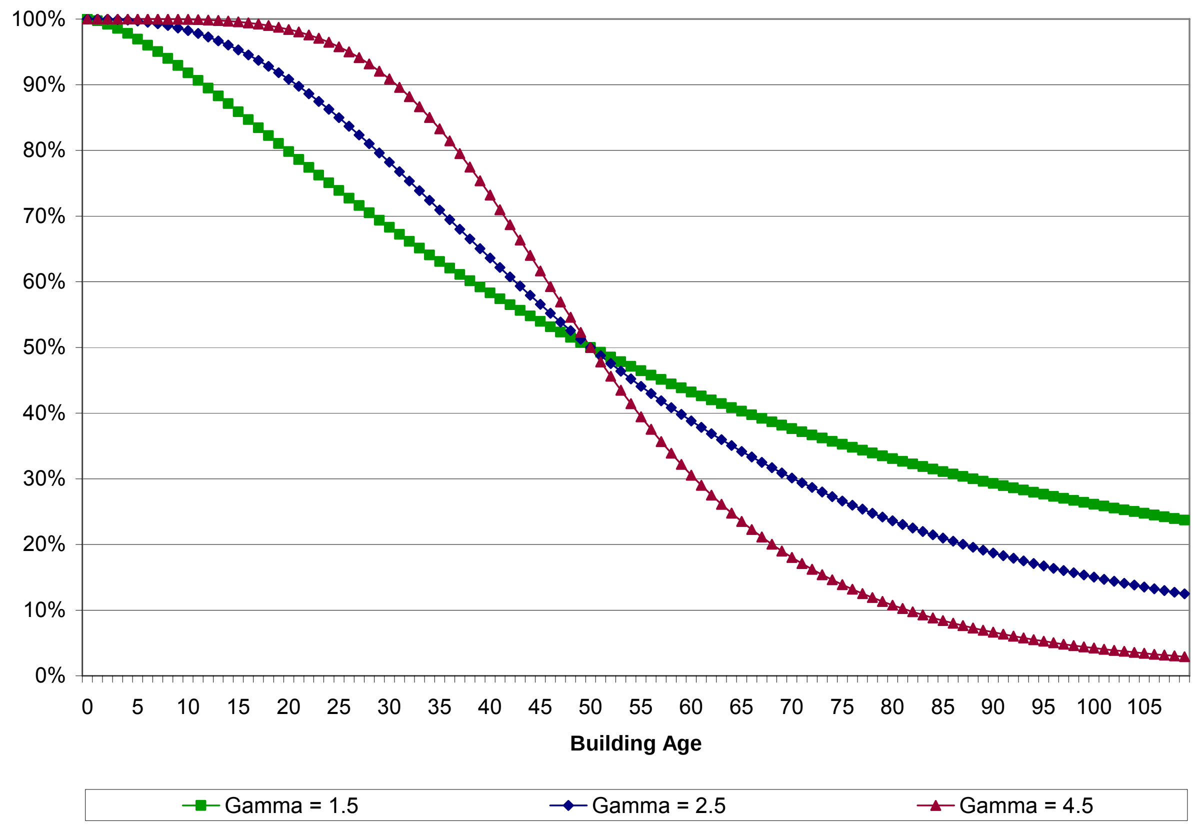
Figure 10. Floorspace Survival Function Sensitivity to Median Building Lifetimes (percent surviving)



Existing floorspace retires over a longer time period if the median building lifetime is increased or over a shorter time as the average 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 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. This implies greater numbers of buildings retiring at or very near the average lifetime. Large values of gamma should be avoided, as this implies 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. Negative values of gamma will not produce a decay or retirement function but rather a penetration function with increasing values. A gamma value of zero yields a straight horizontal line at the 50 percent share mark. Such a value implies that immediately after construction only half the floorspace remains, but it survives forever and therefore has no realistic economic meaning. Hence, gamma must be restricted to values greater than zero for the purposes of the NEMS Commercial Module.

Figure 11. Alternative Gamma Assumptions and Results (percent surviving)



The gamma parameter impacts 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 Commercial Sector Demand Module 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 4.

Table 4. Floorspace Survival Parameters

Building Type	Median Building Lifetime (years)	Gamma
Assembly	80	1.8
Education	80	2.6
Food Sales	65	2.5
Food Service	65	2.5
Health Care	65	2.3
Lodging	69	2.0
Large Office	73	2.0
Small Office	73	2.0
Mercantile/Service	65	1.8
Warehouse	80	1.6
Other	75	2.5

Surviving floorspace from previous years depends on both the composition of the base year (2003) CBECS stock and all new floorspace added between 2003 and the current year of the projection. In addition, survival characteristics vary among building types. Specifically, in order to calculate the surviving floorspace in a given year, it is necessary to consider the amounts and building types of all floorspace by vintage range, as well as the corresponding survival parameters. This is accomplished in the Commercial Module 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 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. The mathematical expression of the Logistic Building Survival Function is given by Equation B-1 in Appendix B.
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 is simply the inverse building retirement, and is performed using Equation B-2 of Appendix

B. Basically, if the age of a given 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:

$$Surviving\ Stock = (Original\ Stock) \cdot (Surviving\ Proportion) \qquad \textbf{(2)}$$

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 (described below) to produce a total history of new additions to floorspace, starting with the original stock of the oldest vintage (currently 1825) 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 prior year into the current year of the projection. This is accomplished using the calculation shown by Equation B-3 in Appendix B.

In order to calculate new additions to floorspace in the current projection year, the surviving floorspace calculated above is combined with the total floorspace projection provided by MAM as follows:

1. Within each Census division, the total amount of floorspace for each CBECS building type is calculated so as to change from the prior year to the current year by the same proportion exhibited by the corresponding combination of MAM building types. The mapping from the MAM building types to the CBECS building types is represented by a transformation matrix named DRItoCBECS. The thirteen building types projected in the MAM are: Amusement, Automotive, Dormitory, Education, Health, Hotel, Manufacturing, Miscellaneous, Office, Public Service, Religious, Store, and Warehouse.[20] New additions are obtained by subtracting the surviving floorspace projection from the total CBECS floorspace projection. For reasons described below, this is merely the first estimate of new additions to CBECS floorspace. The calculation is illustrated by Equations B-4 and B-6. Equation B-5 simply prevents negative new additions by replacing such occurrences with zero.
2. Due to differences between the CBECS and MAM data sources, the results obtained in the previous step do not guarantee that the total floorspace growth rate for each entire Census division will be in agreement with the MAM projection. Therefore, the growth rates by building type obtained in the previous step are uniformly modified within each Census division to achieve agreement between the Commercial Module and the MAM Census division level growth rate projections. This is accomplished using Equations B-7 and B-8.
3. New additions to floorspace for each CBECS building type are obtained by subtracting the floorspace projected as surviving into the current year from the total floorspace in the current year calculated in step 2, as shown by Equations B-8 and B-9, completing the

[20]The Commercial Module does not use the floorspace projection for manufacturing buildings provided by the MAM. Energy consumption in manufacturing buildings is included in the NEMS Industrial Demand Module.

projection of new floorspace. The final value obtained for total floorspace is then given by Equation B-10.

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 Commercial Module partitions energy-consuming activities in the commercial sector into ten services. For reference, these are:

Index	Name	Category
1	Space Heating	(Major)
2	Space Cooling	(Major)
3	Water Heating	(Major)
4	Ventilation	(Major)
5	Cooking	(Major)
6	Lighting	(Major)
7	Refrigeration	(Major)
8	Office Equipment - Personal Computers	(Minor)
9	Office Equipment - Other than Personal Computers	(Minor)
10	Other	(Minor)

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 (2003) energy use intensities (EUIs), base year efficiencies of equipment, efficiencies of building shells, short-term price elasticities, and weather.[21] 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 a given service for a defined area. Currently the model uses EUI estimates developed from CBECS 2003 building-level consumption estimates and conditional demand analysis of the CBECS 1995 consumption survey disaggregated by service, fuel type, building type, and Census division.[22] The concept

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[21]Impacts on service demands due to 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.

[22]Energy End Use Intensity estimates for the 2003 CBECS are not yet available and those for the 1999 CBECS are not available at the level of detail required for *AEO2007*. The EUI estimates for *AEO2007* were derived by applying the results of the CBECS 1995 conditional demand analysis to the CBECS 2003 building-level consumption estimates. The results were then adjusted to account for equipment replacement, new construction, changes in operating hours, and weather differences between 1995 and 2003.

that fuel is consumed in commercial buildings in order to satisfy demands for the services enumerated above is central to the model. Service demand is defined as Btus out (amount of delivered energy). Equipment efficiency or equipment Coefficient of Performance (COP) of the technologies that meet required service demands, together with the distribution of that equipment and the levels of service demanded, determines the fuel consumption, or Btu input. Efficiency is defined as the ratio of Btus out to Btus 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 the 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 Btus in and that used for lighting 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 is assumed to remain constant for a given service in a given 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 and fuel price elasticity, as described below.

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

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

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 Census division level equipment market shares across the different building types. In addition, since the model accommodates fuel switching, the total SDI for the service must be calculated, rather than an SDI corresponding to each fuel used in 2003. The basic calculation illustrated by Equation 3 is carried out by evaluation of Equations B-11 through B-20 in Appendix B for each major service.

Minor services of Office Equipment and "Other" are modeled at a level of detail coarser than that performed for the major services. In particular, specific discrete minor service technologies are not characterized within the Commercial Module; instead, the efficiency of the composite mix of technologies for a given minor service is modeled as evolving relative to its base year (2003) 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-21.

The basic computation of service demand for a given service in a given category of floorspace (new or surviving) is the same for major and minor services, namely:

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

The computation illustrated above is accomplished by evaluating Equations B-22, B-27, B-35, and B-36.

Building shell efficiencies for new construction are user inputs that can be modified to generate scenarios to reflect a variety of conservation policy options such as increased insulation or weather-stripping or new highly energy-efficient construction materials. Building shell improvements are assumed to affect service demands for both space heating and space cooling. However, Commercial buildings are typically not as "shell-driven" as residential buildings (they have less surface area per conditioned cubic volume), and as commercial building shell efficiency improves, more internally generated heat (from lighting, computer equipment, people, etc.) must be removed by air conditioning equipment. These two factors often cause shell improvements to increase cooling loads while heating loads are reduced. As a result, an average cooling load change is calculated based on the heating shell efficiency index. The source of data for calculating the differential cooling effect is a report developed for the U.S. Department of Energy by Lawrence Berkeley National Laboratory.[23]

The present shell efficiencies for existing buildings are indexed to the average 2003 values by building type and Census division. The heating shell efficiency indices are modeled as increasing to user-specified values in 2030. Current building practices, rates of adoption for building codes, research, development, and deployment programs focusing on shell improvements, the "green building" movement, and the long-lived nature of commercial buildings are all considered in selecting the level of shell improvement. For *AEO2007*, floorspace surviving from the base-year floorstock is assumed to improve a maximum of 5 percent over the 2003 stock average by 2030, and new floorspace is assumed to improve 7 percent by 2030 relative to the efficiency of new construction in 2003. Heating shell efficiencies are then translated into cooling shell efficiencies using coefficients based on averaging the changes in cooling loads caused by an improvement to the thermal integrity of the shell. Changing shell efficiencies impact Space Heating and Space Cooling service demands as follows:

$$Service\ Demand = (Service\ Demand\ with\ 2003\ shell)\cdot(Shell\ Efficiency\ Index) \quad \textbf{(5)}$$

The calculations involved in computing the appropriate shell efficiency index and evaluating the expression illustrated by Equation 5 are accomplished using Equations B-23 through B-26 and Equations B-28 through B-30.

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[23] Sezgen, O., E.M. Franconi, J.G. Koomey, S.E. Greenberg, A. Afzal, and L. Shown, Lawrence Berkeley National Laboratory, *Technology Data Characterizing Space Conditioning in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0*, LBL-37065, (Berkeley, CA, December 1995).

The computation of service demand for space cooling, ventilation, and “Other” services is adjusted to account for the requirements of data centers that house large numbers of server computers and other internet-related equipment. Data centers are included in the large office category of commercial buildings with their proportion given by Equation B-31. The adjustment to account for increased service requirements is shown in Equations B-32 and B-33. Projections of data center floorspace as a share of large office buildings and estimates of additional cooling, ventilation, and “Other” needs are developed based on the literature referenced in Appendix A. Projections for the computers and other office equipment used in data centers are included in the Office Equipment projections discussed below.

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 captured, and is accounted for using Equation B-34

While the market for major services is generally assumed to be saturated, additional penetration of the minor services of Office Equipment (both PC and NonPC) and "Other" is modeled. Projections of continuing market penetration are prepared offline for Office Equipment and the non-specific portion of “Other” as described in Appendix A, and incorporated into the service demand projection for these minor services using Equations B-37 and B-38.

Service demand projections, including continuing market penetration, for several specific categories of electricity use within “Other” are based on electricity consumption estimates and projected national-level trends from a September 2006 study completed by TIAX LLC.[24] The specific categories modeled and their corresponding category indices are provided in Table 5.

Table 5. Miscellaneous Electricity Use Categories

Category Index (mc)	Electricitiy Use
1	Coffee Brewers
2	Distribution Transformers: Dry-type
3	Distribution Transformers: Liquid
4	Non-road Electric Vehicles: Lift Trucks, Forklifts, Golf Carts, and Floor Burnishers
5	Medical Imaging: Magnetic Resonance Imaging (MRI)
6	Medical Imaging: Computed Tomography (CT) Scanners
7	Medical Imaging: X-ray Machines
8	Elevators
9	Escalators
10	Municipal Water Services: Water Distribution and Purification, Wastewater Treatment

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

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, 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 all types of commercial floorspace and by the efficiency standards included in EPACT05.

The computation of service demand for the specific categories of miscellaneous electricity use, except for municipal water services, is carried out by evaluating Equations B-39 through B-44. Projected electricity use for municipal water services is calculated as part of non-building energy consumption as illustrated in equations B-130 through B-132.

The portion of service demand satisfied by solar water heaters is computed endogenously as solar water heating technologies are included in the Technology Choice Submodule. However, the portion of service demand satisfied by solar space heating and daylighting is computed 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, the effects on consumption of conventional fuels can be determined. The calculations involved in modeling the penetration of solar services are performed by Equations B-45 and B-46.

The short term price elasticity of demand is currently provided for all end-use services. The parameters included in the Commercial Module 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 other minor uses of electricity. These values are representative of estimates provided in the literature as referenced in **Table A-3**. The elasticity parameters represent the short-term price responsiveness of the aforementioned service demands in the model. The values for the elasticities must necessarily be non-positive since the services are normal goods, meaning that, as fuel prices increase, the quantity demanded of energy services declines. The full elasticity effect is graduated or “lagged” over a three-year period to allow the degree of consumer response to vary with significant changes in fuel prices. In order 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 a given year is shown in Equation B-103. The service demand elasticity application is illustrated by Equation B-104. Equation B-104 also illustrates the modification of pure price elasticity to account for the fact that improving equipment and shell efficiencies reduce the actual cost of meeting certain service demands. Incorporation of this "take-back" or "rebound" effect, and the weather correction (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. The paper "Price Responsiveness in the AEO2003 NEMS Residential and Commercial Buildings Sector Models," available on EIA's web site, provides a thorough discussion of both short term and long term price response in the Commercial Demand Module.[25]

The final responsibility of the Service Demand Submodule is to determine the amount of service demand in surviving floorspace that becomes unsatisfied in the current projection year due to failure of equipment. A simplified equipment vintaging scheme is employed, 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 Commercial Module assumes 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 the surviving portion, for satisfaction by appropriate decisions in the Technology Choice Submodule. The calculation of this split is performed by Equations B-47 and B-48.

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 10 distributed generation technologies. The characterized technologies include: photovoltaics, natural gas (fuel cells, reciprocating engines, turbines and microturbines), diesel engines, coal fired CHP, municipal solid waste and wood generators, and hydroelectric.[26]

Estimates of CHP electricity generation for historical years by technology, Census division and building type are developed 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 this 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 (Equation B-153). 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-155 and B-156).

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[25] See http://www.eia.doe.gov/oiaf/analysispaper/elasticity/index.html.

[26] Assumed technology characterizations for natural gas-fired and oil-fired CHP technologies are currently based on Discovery Insights, LLC, *FINAL REPORT Commercial and Industrial CHP Technology Cost and Performance Data Analysis for EIA's NEMS*, prepared for U.S. Department of Energy – Energy Information Administration, February 2006. Solar photovoltaic specifications are from Solar Energy Industries Association, *Our Solar Power Future – The U.S. Photovoltaic Industry Roadmap through 2030 and Beyond*, September 2004.

For projection years, distributed generation technology penetration rates are estimated by Census division, building type, and building size category and vary depending on floorspace vintage (newly constructed versus existing floorspace). Technology penetration rates for new construction are determined by how quickly an investment in a technology is estimated to recoup its flow of costs. Penetration parameters are allowed to vary by technology and are as high as 30 percent when investment pay back is one year. Investments that pay back in less than a year may achieve even greater penetration, up to a maximum of 75 percent. That is, up to 75 percent of new construction in any year can potentially include a specific distributed generation technology. Penetration into existing floorspace is limited, by assumption, to a much lower rate based on the magnitude of the stock of existing floorspace relative to new construction in any given year and the added complexities when considering installation of a distributed generation system in an existing building. The limit is the lesser of 0.5 percent or the penetration rate into new construction divided by 50. The limit is in effect if penetration into new construction exceeds 25 percent.

For new construction, penetration rates are a direct function of the number of years required to achieve a cumulative positive cashflow for the investment. This approach is related to, but different from the "simple payback" concept. Simple paybacks are merely the investment cost divided by estimated annual savings. The cumulative positive cashflow approach incorporates financing assumptions in the calculations and can yield payback estimates that are faster than what would be computed as the simple payback (it can also yield "infinite" paybacks if the cumulative cash flow never becomes positive). The working assumption is that for new construction, investment in distributed generation technologies is rolled-in with the mortgage. The calculations for new construction assume the financing of such investments under commercial mortgage rate parameters supplied in the generation technology input file. In addition to energy savings, the timing and magnitude of tax effects are included in the cashflow calculation, thus allowing the modeling of tax policies.

For each potential investment decision, a cashflow analysis covering 30 years from the date of investment is made (see Equations B-140 through B-176 for details). The calculations include the costs (down payments, loan payments, maintenance costs and fuel costs) and returns (tax deductions, 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. If the return is positive, then the cumulative net cashflow increases. For current technologies the purchase costs and investment returns are such that the first year's cash flow is negative. Thus, the technology starts out with a negative year 1 cash flow which will then either increase or decrease based on the net economic returns. Tax credits are modeled as one-time payments to the commercial entity in year 2 of the investment, assuming that a wait on average of 1 year is needed to receive the credits. Tax credits can have a major effect on increasing the rapidity of achieving a positive cumulative net cashflow. Once the 30-year analysis is complete, the number of years required to reach a positive cashflow is passed on to the penetration function for newly constructed floorspace.

The allowed depreciation treatment for distributed generation technologies can 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 distributed generation technologies be depreciated using the straight-line depreciation method. To facilitate the modeling of potential tax policies, the Commercial Demand model 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 (i.e. declining balance method) by providing an input for each projection year. A value of 100 percent indicates straight-line depreciation while a value greater than 100 (200 or 150 percent) indicates the declining method. For *AEO2007*, the depreciation treatment has been defaulted as straight-line depreciation with a tax life of 39.5 years, based on current legislation. The only exception to this rule is photovoltaic technology, which is depreciated under a Modified Accelerated Cost Recovery System (MACRS) classification using a 5-year tax life and 200 percent declining balance depreciation as allowed by current tax laws. The depreciation calculation is illustrated in Equations B-148 through B-150.

The penetration function for new construction is assumed to have a "logistic" shape that produces slow initial penetration followed by a period of more rapid growth and ending with a tapering-off effect (Equation B-169). The alpha and *penparm* coefficients control the shape and the maximum penetration allowed, respectively. The coefficients for maximum penetration vary depending on whether the distributed generation technology uses natural gas or solar energy versus some other fuel. The other technologies like coal and diesel will generally be subject to environmental constraints and as such are not expected to grow significantly over the projection horizon. Thus, maximum penetration for them has been set extremely low to agree with this expectation. The maximum penetration for the natural gas and solar technologies has been limited to 75 percent of new construction when investments pay back in less than one year to reflect the fact that distributed generation will not be appropriate for all buildings, no matter how quickly an investment may pay back. The technology-specific penetration function coefficients are supplied in the generation technology input file as defined in Appendix A.

The endogenous driver for penetration is the number of years calculated until a positive cumulative cashflow is achieved. In many cases, this may never occur, and the number of years is set to 30. The result is that as economic returns improve, the period required to meet the positive cumulative cashflow requirement is shortened and penetration increases. Figure 12 represents the penetration function under current assumptions of a maximum assumed penetration of 75 percent for new construction.

Economic returns and hence penetration rates are potentially affected by "learning cost effects" that are modeled for emerging distributed generation technologies. Learning effects reduce projected installed costs as an emerging technology gains "maturity" from increasing cumulative shipments over time. Such effects are often referred to as stemming from "learning-by-doing."[27] There are currently three emerging distributed generation technologies for which learning effects are included, photovoltaics, fuel cells and microturbine generators.

Operationally, distributed generation technology costs for emerging technologies are represented as the minimum of 1) a "menu" cost read in from the distributed generation technology input file, and 2) an endogenous cost that incorporates learning effects (Equation B-140). The endogenous learning cost incorporates an inverse relationship between installed cost and cumulative shipments. Thus, the modeled installed cost can be lower than the menu-input cost depending upon the magnitude of cumulative shipments (which are in turn driven by technology penetration rates). The learning cost function is driven by cumulative shipments and includes

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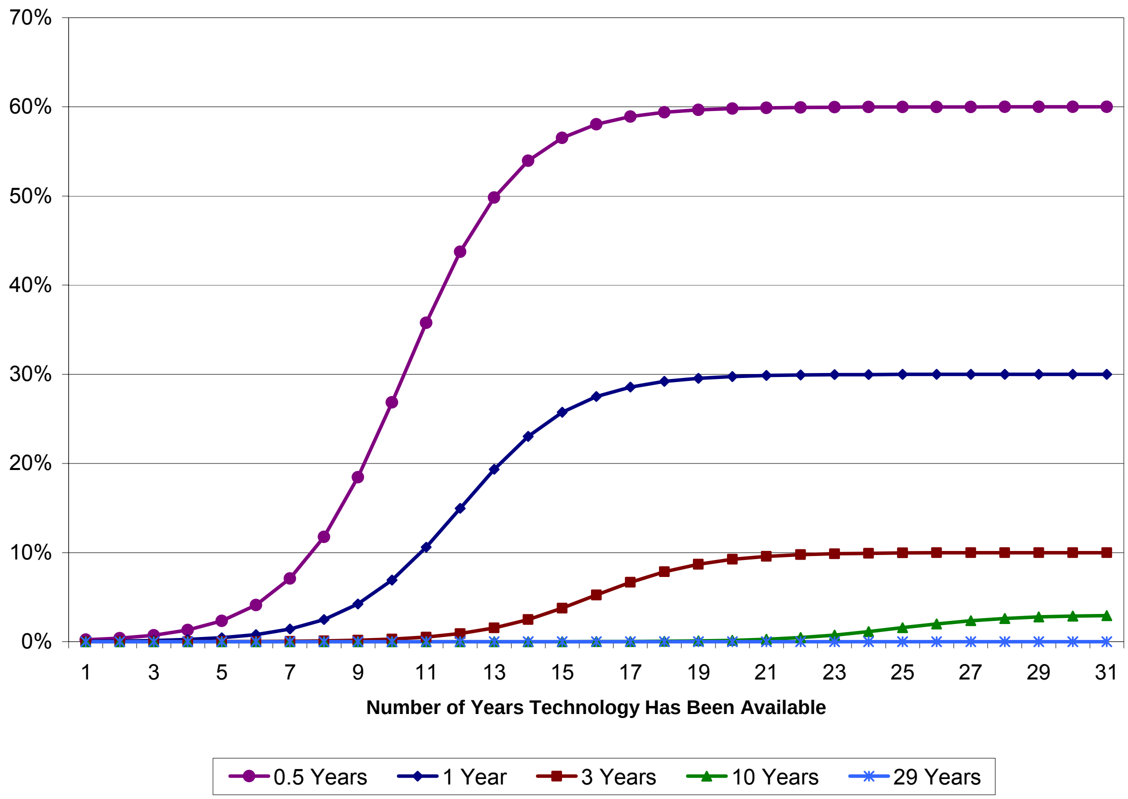
[27]For a review of the literature on learning costs as well as empirical results for buildings equipment see Richard G. Newell, "Incorporation of Technological Learning into NEMS Buildings Modules," Energy Information Administration, Washington, DC, September 29, 2000.

two parameters, alpha and beta. Alpha represents the first unit cost and beta is the learning "parameter" which determines the sensitivity of cost changes to cumulative shipments. Since first 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.

Figure 12. Distributed Generation Technology Penetration Rate Curves for New Construction for Various Years to Positive Cash Flow (percent penetration)



The calibrated first cost estimates are given in **Table 6** along with the learning parameters. The larger the learning parameter, the greater the cost declines for a given percentage increase in cumulative shipments. We are unaware of any studies that apply directly to the type of commercial generating equipment modeled. Thus, the beta learning parameters were judgmentally chosen. Dutton and Thomas (1984)[28] found parameters in the range of those 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 micro turbines was assumed so as to yield smaller cost declines since that technology is already the least expensive and similar to gas turbine technology that is much more "mature" than any of the three emerging technologies represented.

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[28]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.

Table 6. Distributed Generation Technology Learning Function Parameters

Technology	Calibrated First Cost (per kw)	Learning Parameter (beta)
Photovoltaic Systems (PV)	$14,000	0.2
Fuel Cells	$10,000	0.2
Micro Turbines	$2,250	0.15

In terms of the NEMS projections, investments in distributed generation reduce purchases of electricity from the "supply-side" of NEMS. If the investment is photovoltaic, renewable energy replaces energy input to electric utilities for the self-generated amounts. If generated by fuel cells or other fuel-consuming technology, utility consumption of fuel is replaced by commercial fuel consumption. Fuel consuming technologies also generate waste heat which is assumed to be partially captured and used to offset commercial energy use for water heating and space heating. Depending on a fuel consuming technology's performance characteristics, the substitution of self-generation for utility generation could increase primary energy consumption. For photovoltaics, primary energy consumption is lower than what would otherwise be projected.

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. One feature of the current approach that distinguishes it from alternative modeling approaches is its representation of the heterogeneity of agents in the commercial sector. The NEMS Commercial Sector Demand Module segments commercial agents using three behavior rules and seven distinct risk-adjusted time preference premium categories. This type of segmentation incorporates the notion that all agents do not consider the same set of parameters in the optimization within the commercial sector. Some participants may display specific behavior due to 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.

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 Commercial Sector Demand Module 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 given total cost, a dollar increase in capital cost must imply more than a dollar decrease in fuel and O&M costs since the dollar spent today for capital is worth more than any future dollar. Therefore, a tradeoff in the form of additional reduction in other costs is necessary in order for 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 fuel costs over the expected economic lifetime of the equipment.

The algorithm is designed to choose among a discrete set of available technologies for each decision. The Technology Choice Submodule computes the 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 Commercial Sector Demand Module is:

$$\begin{aligned}\frac{Annualized\ cost}{unit\ of\ delivered\ service} &= (annuitized\ purchase\ \&\ installation\ cost\ component) \\ &+ (yearly\ O\&M\ component) \\ &+ (expected\ yearly\ fuel\ cost\ component)\end{aligned} \qquad \textbf{(6)}$$

The unit of service demand referred to above that is used in the Commercial Module calculations is thousand Btu 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 that used for ventilation 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 Commercial Sector Demand Module 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 Commercial Module 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, although lighting is the only service to use technologies specified as Adolescent or Infant at the current time. The calculation of unit costs using the cost trend function is presented in Equation B-55.

The electricity prices used to develop the annualized fuel costs, in the default mode, are end-use specific prices developed by weight-averaging time-of-day rates by expected time-of use patterns. The incorporation of prices relevant to a particular end-use service accommodates the move to competitive marginal cost pricing expected as a result of the deregulation of electricity 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-60. For decisions regarding space heating and cooling equipment, the calculation includes a shell efficiency factor, incorporating the effects that building shell improvements have on annual fuel costs. The shell efficiency factor, illustrated in Equations B-56 and B-57, uses the same shell efficiency indices calculated in the Service Demand Submodule. The effective hurdle (implicit discount) rate used in Equation B-60 is given by Equations B-58 and B-59 and discussed in the section on Risk-Adjusted Time Preferences.

The cost relevant to consumers and the menu of technologies varies 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. There are nine combinations of commercial consumer behavior rules and decision types with which technology choice decisions are made in the Commercial Module. These are presented in **Table 7** and described in greater detail below.

Table 7. 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 Commercial Sector Demand Module 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. These behavior rules are:

- 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, minimize 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 Commercial Sector Demand Module segments consumers into three behavior rule categories. Ideally, survey data would provide an indication of 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 CBECS 1995 and CBECS 1999. Data regarding the ownership and occupants of commercial buildings forms 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. The CBECS data is combined with other data characterizing consumer behavior obtained from published literature to develop the behavior rule proportions incorporated in the Module.[29] Changing these proportions impacts final consumption estimates.

The supporting data from CBECS 1999, including building stock ownership patterns for 1999, is presented in **Table 8**. The categories provided are:

- Total Floorspace of All Buildings
- Total Floorspace of All Nongovernment Owned Buildings
- Owner Occupied
- Nonowner Occupied

Specific ownership categories are developed from this data, including but not limited to:

- Nongovernment, Non-owner Occupied, which is the difference between Total Nongovernment Owned and Nongovernment Owner Occupied; and
- Government Owned, which is the difference between Total Floorspace and Nongovernment Owned.

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 8 and this discussion.

[29]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 complete data set for the 2003 CBECS was not available in time to update the analysis of building ownership patterns for *AEO2007*. The 2003 building ownership patterns will be incorporated into behavior rule assumptions for *AEO2008*.

Table 8. 1999 Floorspace Ownership and Occupancy

Building Type	Total Floorspace (MM sq. ft.)	Government Owned (MM sq. ft.)	Government Owned percent	Nongovernment Owned: Total (MM sq. ft.)	Total percent	Owner Occupied (MM sq. ft.)	Owner Occupied percent	Non-owner Occupied (MM sq. ft.)	Non-owner Occupied percent	Self-Built percent	Speculative Developer percent
Assembly	7,798	1,618	20.7%	6,180	79.3%	5,500	70.5%	680	8.7%	92.0%	8.0%
Education	8,651	5,444	62.9%	3,207	37.1%	2,640	30.5%	567	6.6%	99.0%	1.0%
Food Sales	994	5	0.5%	990	99.5%	687	69.1%	303	30.5%	50.0%	50.0%
Food Service	1,851	89	4.8%	1,763	95.2%	1,326	71.6%	437	23.6%	50.0%	50.0%
Health Care	1,865	376	20.2%	1,489	79.8%	1,360	72.9%	129	6.9%	85.0%	15.0%
Lodging	4,521	421	9.3%	4,100	90.7%	3,178	70.3%	922	20.4%	80.0%	20.0%
Mercantile/Service	13,786	873	6.3%	12,913	93.7%	5,307	38.5%	7,606	55.2%	25.0%	75.0%
Office	13,097	1,636	12.5%	11,461	87.5%	5,228	39.9%	6,233	47.6%	30.0%	70.0%
Warehouse	10,477	576	5.5%	9,900	94.5%	5,425	51.8%	4,475	42.7%	50.0%	50.0%
Other	4,298	1,306	30.4%	2,991	69.6%	997	23.2%	1,994	46.4%	50.0%	50.0%
TOTAL:	67,338	12,344	18.3%	54,994	81.7%	31,648	47.0%	23,346	34.7%	55.1%	44.9%

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, 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 simply replace the existing technology with the same technology.

The general description of the technology choice procedure described above does not mean that all consumers simply minimize the costs that can be measured. There is a range of economic factors that influence technology choices that cannot be measured. 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 but non-measurable costs associated with gathering information for purchase decisions, and managerial attention.

Decision Types and Their Relationship to Behavior Rules

Besides providing behavior rules to determine how consumers select technologies to meet their service demands, the model must furnish a rationale for purchasing the equipment in the first place. The reasons for purchasing equipment are referred to as decision types and described below. There are three equipment purchase decision types for commercial sector consumers. These decision types are:

- 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 computed 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 is accomplished by Equations B-49 through B-53 given 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 using Equation B-62. 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-63. 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-66. Similarly, the identification of least cost models for each technology for the consumers following the same technology rule is illustrated by Equation B-64. 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-68.

For equipment replacement decisions, consumers using the least cost behavior rule choose from among all current technologies, as illustrated again by Equation B-62. Consumers using the same fuel behavior rule choose from among current technologies which 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-67. 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-69.

For the retrofit decision, which involves the choice of retaining equipment that continues to function, or replacing it with equipment in order to reduce costs, the costs of purchasing new equipment as described above must be compared against the cost of retaining existing equipment. In order 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, since it is 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 Commercial Sector Demand Module technology characterization database as a specified fraction of the original purchase and installation cost, and is annualized over the equipment lifetime. The resulting calculation of the annualized cost of retaining the existing equipment is given by Equation B-72. As in the calculation of the annualized cost of new equipment, the annualized cost of retaining existing space heating or cooling equipment includes the shell efficiency factor illustrated in Equations B-56 and B-57, incorporating the effects that building shell improvements have on fuel costs, and the effective hurdle rate given in Equations B-58 and B-59.

For the equipment retrofit decision, consumers using the least cost behavior rule choose from among all current technologies, comparing the cost of each as expressed by Equation B-60 against the cost of retaining the existing equipment as expressed by Equation B-72, and choosing the least cost result, as illustrated by Equation B-73. 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-76. Two options are available in the Commercial Sector Demand Module to represent the choice behavior of consumers using the same technology behavior rule for the equipment retrofit decision. One option, used in the *AEO2007* 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-75. Alternatively, all consumers using the same technology behavior rule may be assumed to retain their existing equipment, as indicated by Equation B-78. The choice of methods is specified through the Commercial Module 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 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 Commercial Sector Demand Module is designed to accept a distribution of risk-adjusted time preferences as input. This is a discrete distribution; 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.[30] The risk-adjusted time preference distribution is modeled independently of the behavior rules. The risk-adjusted time preference results in differences in consumer preferences between capital costs (paid initially)

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[30] There is a substantial literature that attempts to explain why consumers (in the general sense of the word to include businesses too) fail to invest in energy-efficient equipment that seems to make economic sense at prevailing market interest rates. There are several reasons for this to be the case such as uncertainty about future energy prices, lack of information regarding the performance and even cost of particular types of energy-efficient equipment, estimated installed costs might not include disruption costs for businesses, energy costs are typically a small share of commercial business expenses and investments affecting core business income are often considered more important then efficiency investments, and uncertainty about future technologies (buying too soon may “lock in” to a less efficient technology). For a good review of these and other issues and reasons see: Jaffee, A. B. and R. N. Stavins (1994). "The Energy-Efficiency Gap: What Does it Mean?" Energy Policy 22: 804-810.

and fuel and O&M costs (incurred over the lifetime of the equipment). The value of the consumer's risk-adjusted time preference interest rate premium influences the annualized installed capital cost through an annuity payment financial factor based on the 10-year Treasury bond rate, the risk-adjusted time preference premium, and expected physical equipment lifetime. The sum of the 10-year Treasury bond rate and the consumer risk-adjusted time preference premium is referred to as the implicit discount rate, i.e., the empirically based rate required to reflect actual purchases—the one implicitly used. 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.

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. The values currently used in the Commercial Sector Demand Module have been developed using case studies on the payback period or risk-adjusted time preferences regarding the adoption of a specific technology. For *AEO2007*, the distribution of consumer risk-adjusted time preference premiums is assumed constant over the projection horizon. However, 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 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 Commercial Module 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 (2003), 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 Equations B-58 and B-59. Parameter assumptions for *AEO2007* result in a 30 percent reduction in the nonfinancial portion of a hurdle rate with a doubling of fuel prices, down to a total hurdle rate of 15 percent, the assumed financial discount rate. If the risk-adjusted time preference premium input by the model user results in a hurdle rate below 15 percent with base year fuel prices, no response to increasing fuel prices is assumed.

Consolidate Choices From Segments

Once the technology choices have been made for each segment represented for a given end-use service, these choices must be consolidated in order to obtain equipment market shares by building type, Census division, and decision type for the end-use. From these market shares, average efficiencies of the equipment mix and fuel shares may be obtained, with which the Consumption Submodule calculates 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. Since a given risk-adjusted time preference segment makes only one equipment selection for a given decision type and behavior rule, the market share of a given equipment type is computed 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 is the calculation performed by Equations B-65 through B-69 and B-76 through B-78, with 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 is done using Equations B-70, B-71, and B-79 to obtain equipment market shares for the new, replacement, and retrofit decisions, respectively. This and the previously-described consolidation may be viewed as weighted sums, using as weights the quantities described in Table 9.

Table 9. Consolidating Service Demand Segments

Variable by Which Service Demand was Segmented	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, and deserves separate mention. The purchase decision of heat pumps is integrated to provide both space heating and space cooling. This is desirable because selection of 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 Commercial Module using the following approach:

First, heat pumps are assumed to provide both space heating and cooling when purchased, but 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 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 captures the fact that the heat pump provides both space heating and space cooling, 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-54.

During the technology choice process for satisfying space cooling service demands, heat pumps are excluded from selection due to 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. This is accomplished 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, and hence their market shares of cooling service demand. This calculation is performed by Equation B-80. In order 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-81 through B-83.

Fuel shares of service demand for the major services and fuels are calculated in a straightforward manner, by simply summing the equipment market shares of service demand of equipment using a given fuel. This is the calculation performed by Equation B-84 within the decision type segments by end-use, fuel type, building type, and Census division, and by B-86 consolidated across decision types. Equations B-92 through B-94 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-85, B-88 through B-91, and nationally by end-use and fuel using Equation B-95. 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 consideration of individual equipment choices given to the major services. As described previously, the 2003 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-96. Projected changes in PC and Other Office Equipment energy consumption are explicitly included in the PC and Other Office Equipment projections described in Appendix A under Market Penetration, so the EffGrowthRate is set to zero for the both office equipment end-use services. Expected efficiency improvements are also explicitly included in the trend projections for specific categories within the "Other" end-use service. Efficiency improvement for the non-specific portions of the "Other" end-use service is set to zero due to 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 given Census division and year, and office equipment services are assumed to use only electricity, as illustrated by Equation B-97.

Technology Menu

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, and technology cost trend parameters are specified exogenously. 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 therefore may 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, with unit costs either fixed or declining according to the appropriate cost trend function. The other equipment characteristics are assumed fixed for a given technology and vintage once it is commercially available.

These technology characterizations are important, since improper estimation can cause substantial aberrations in market behavior over the projection period. As an example, assume that a new high efficiency piece of equipment becomes available in a specific projection year. If the costs of the new piece of equipment are too low relative to other equipment for the service then too many new, replacement, and retrofit decisions will be directed to this equipment, in turn unrealistically reducing overall energy consumption and increasing the average equipment efficiency, although the behavior rule proportions dampen this effect. 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 2003 initial historical market shares are based on an analysis of CBECS 2003 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 natural gas-fired water heater currently available may no longer be available in 2004 due to federally mandated minimum equipment efficiency standards.

An option to allow endogenous price-induced technology change 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 Commercial Module 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, i.e., 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 (e.g., those projected for 2008) to ensure that future improvements can not become available before the persistent price change is projected to occur. Equations B-98 through B-100 illustrate the calculations needed to move an availability date forward through price-induced technology change. Although no price-induced change would have been expected using *AEO2007* reference case fuel prices, the parameter was set to 0 years for the *AEO2007* model runs, effectively assuming there would be 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. Additionally, the End-Use Consumption Module 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-101, makes use of the definition of average efficiency to obtain the projected consumption by fuel, end-use, building type, Census division and year, by simply dividing that portion of the end-use service satisfied by a given fuel by the average efficiency of equipment using that fuel. A value of zero for the average efficiency indicates that no equipment consuming the given 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-102.

The basic estimate of fuel consumption described above is that projected 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 (2003), and consumers were only concerned with fuel prices in so far as they impacted the equipment purchase decisions. Since conditions other than those mentioned above vary with time and 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 heating 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. While 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 Module because of the direct proportionality between service demand and fuel consumption, as can be seen in Equation B-101; that is, a percentage change in service demand corresponds to the same percentage change in fuel consumption. 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-103 illustrates the function used to calculate the short-run elasticity adjustment. The first term in Equation B-104 shows the application of the short-run price elasticity of demand to modify the basic consumption estimate obtained by Equation B-101.

Another consideration that affects the consumer's demand for services is known as the "rebound," or "takeback" effect. While fuel price increases can be expected to reduce demand for services, this 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 due to 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-104. Because these modifications to the basic consumption estimate are each multiplicative, Equation B-104 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. While the rebound effect due to equipment efficiency improvement is considered for the end-use services of space heating, space cooling, water heating, ventilation, cooking, and lighting, the effect due to 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 Commercial Module are set to -0.15 for these services.[31]

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 (2003) weather and "average" or “normal” weather anticipated for future years. The basis for the weather correction is the number of population-weighted heating and cooling degree days by Census division for the years 1990 through 2005, together with the long term (30 year) average of each to represent normal weather. Because 2003 is the base year for the key Commercial Module parameters, the basic projection for consumption in other years to provide space heating and space cooling is modified by considering the heating and cooling requirements in that year relative to those prevailing in 2003. This is accomplished for heating consumption using a multiplicative factor equal to the ratio of the appropriate degree days, as shown by Equation B-105. Values for 2006 have been extrapolated using data through September of that year. Years after 2006 are assumed to exhibit the long-term average number of population-weighted heating and cooling degree days by Census division. The long-term average is adjusted over the projection period to account for state population shifts. Equation B-106 illustrates the weather correction for space cooling requirements, including an exponential term to reflect the non-linear 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 by equipment directly satisfying the 10 basic end-use services. Consumption of the minor fuels of residual oil, liquid petroleum gas, steam coal, motor gasoline, and kerosene is calculated using a different approach, as is consumption for purposes not yet explicitly modeled. These include 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).

Consumption of the minor fuels is projected using a moving average of previous fuel use, floorspace growth, and price elasticity estimates derived from historical minor fuel consumption and pricing data. An average of the previous six years of consumption is first calculated as illustrated in Equation B-120. The resulting consumption estimate is modified using a price elasticity of demand as shown in Equation B-121 to account for any change in the minor fuel price. The minor fuel price elasticity estimates were developed from historical Census division-level minor fuel consumption and pricing data, obtained from the State Energy Data System, which spans the 23-year period from 1970 to 1992. Finally, the estimate is adjusted by

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[31]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.

floorspace growth as given in Equation B-122 to produce the projection of 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-107 through B-109 to reflect the use of self-generated electricity. Equation B-110 illustrates reduction in space and water heating consumption through use of heat generated by CHP technologies. Equation B-111 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 in order 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 distributed end-use services over a wide area, such as a campus environment. Estimates of the steam energy EUI by Census division, building type, and end-use service for district energy services were prepared separately from those previously described for the standard end-use services. These are used in conjunction with typical efficiencies and fuel shares for the boilers 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-112. 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-113.

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-115. 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-124. 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 and solar energy for electricity generation by photovoltaic systems, as shown by Equation B-125. 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 represents the collection of historical fuel consumption data chosen to serve as a standard for the NEMS system over the historical period of the projection. Additionally, the Benchmarking Submodule provides an option for considering results from EIA's Annual Energy Review (AER) and Short Term Energy Outlook (STEO) for the near term immediately beyond the last year of SEDS data availability. Definitional differences between SEDS and the CBECS, upon which the Commercial Sector Demand Module is based, are used to construct a projection of commercial sector fuel consumption not attributable to end-uses within buildings.

Equation B-126 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-127. This assignment is performed during each year of the projection period for which SEDS data is available. The use of the SEDS data through the year indexed as MSEDYR+1 in these calculations reflects the fact that the AER 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 and natural gas 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 exterior lighting of parking lots. The projection of SEDS-based consumption of electricity and natural gas for non-building uses beyond the last year of SEDS data availability is shown by Equation B-129. The projection of electricity use for municipal water services as a component of non-building uses is illustrated in Equations B-130 through B-132. Non-building use of distillate and minor fuels is not expected to grow at the same rate as commercial floorspace, but instead to remain at a relatively constant level, as illustrated by Equation B-134.

The Commercial Sector Demand Module includes an option to activate benchmarking to that portion of the STEO projection immediately following the last year of historical data. This is accomplished through the setting of a NEMS system-wide parameter named STEOBM and a Commercial Module 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-128 for electricity and natural gas. Equation B-133 gives the corresponding calculation for distillate and minor fuels. An additional option limits STEO benchmarking adjustments to result in projected fuel use that is within 2 percent of the STEO projection, as illustrated in Equation B-135. Equation B-136 shows the addition of the STEO-based incremental component of non-building consumption to the component based on SEDS.

In the event 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 all future years of the projection period. 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. The choice of methods is specified through the Commercial Module user parameter named DecayBM. Calculation of a time-dependent decay factor based on the selection of the various options is illustrated by Equation B-137. Equation B-138 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. For *AEO2007*, the option to benchmark through year 2006 to the STEO projection was chosen with the STEO component of non-building use ramped down to zero by 2008.

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-139.

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 Module. 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, as 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 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. Further information is provided naming the submodule (FORTRAN subroutine) in which the equation is implemented. Definitions are provided as well as classifications (inputs, parameters, or calculated variables) and units of measurement.

Table A- 1. NEMS Commercial Module Inputs and Outputs

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
ACE	B-72	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, 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.	Calculated variable	Non-lighting, non-ventilation: Constant 2004 dollars / (thousand Btu out per hour) / year Lighting: Constant 2004 dollars / thousand lumens / year Ventilation: Constant 2004 dollars / thousand CFM
AE	B-85	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-hrs air delivered / thousand Btu consumed

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
AnnualCostTech	B-60	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, 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.	Calculated variable	Non-lighting, non-ventilation: Constant 2004 dollars / (thousand Btu out per hour) / year Lighting: Constant 2004 dollars / thousand lumens / year Ventilation: Constant 2004 dollars / thousand CFM
AverageEfficiency	B-88	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-17	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 input equipment efficiencies and market shares.	Calculated variable	Non-lighting, non-ventilation: Btu out / Btu in Lighting: lumens / watt Ventilation: thousand CFM hours air delivered / thousand Btu consumed

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
BaseYrPCShrofOffEqEUI	B-12	Service Demand	Proportion of the base year office equipment EUI present in file KINTENS that is attributable to office Personal Computers (PCS). 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 split accordingly.	Input parameter KPARM	Unitless
BehaviorShare	B-70	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
CapacityFactor	B-60	Technology Choice	Equipment capacity utilization factor representing the proportion of time a given service is demanded in a given 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 square feet (MMsqft)
CBECSyear	B-2	COMM	Survey year of CBECS data used as base year data for the Commercial Module. Current value is 2003.	Parameter	Calendar year
CDRatio	B-7	Floorspace	Ratio of MAM floorspace growth rate and first estimate of Commercial Module floorspace growth rate by Census division	Calculated variable	Unitless
CforSrestrict	B-14	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-13	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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
CMAvgAge	B-1	Floorspace	Median building lifetime by building type b.	Input from file KBLDG	years
CMFinalEndUse	B-124	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-125	Consumption	U.S. total Consumption across end-uses, including CHP and district services, by building type and year.	Calculated variable	Trillion Btu
CMFinalUnbenchCon	B-123	Consumption	Unbenchmarked fuel consumption across building types by fuel type, Census division, and year.	Calculated variable	Trillion Btu
CMFirstYr	B-48	COMM	Index of first year of projections. Set to the first year after CBECSyear, the year of the CBECS survey 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 construction for years prior to CBECSyear.	Calculated variable	Million sq ft
CMNonBldgUse	B-127	Benchmarking	Non-building fuel consumption by Census division, fuel, and year.	Calculated variable	Trillion Btu
CMnumBldg	B-45	Service Demand	Number of Commercial Module building types. Current value is 11.	Parameter	Unitless
CMnumMajFl	B-20	Service Demand	Number of Commercial Module major fuels. Current value is 3.	Parameter	Unitless
CMnumVarSDI	B-34	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 1825.	Parameter	Calendar year

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
CMSEDS	B-126	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 (currently 1990-2003). Similar data from the Annual Energy Review (AER) and STEO forecast is present for the years 1989+MSEDYR+1 through 1989+KSTEOYR (currently 2004 through 2006).	Module input from Global Data Structure and file KSTEO	Trillion Btu
CMSurvRate	B-1	Floorspace	Logistic building survival function, giving the proportion of original construction still surviving as a function of the age, and the parameters CMAvgAge and CMGamma.	Calculated variable	Unitless
CMTotalFlspc	B-4	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 square feet
CMUSAvgEff	B-95	Technology Choice	National average equipment efficiency by end use service, fuel, and projection year.	Calculated Variable	Btu delivered / Btu consumed
CMUSConsump	B-118	Consumption	U.S. total fuel consumption by end-use, fuel type, and year.	Calculated variable	Quadrillion Btu
CMUSDistServ	B-114	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-11	Service Demand	Base year Energy Use Intensity (EUI) by fuel type, end-use service, building type, and Census division. Base year = CBECSyear =2003.	Input from file KINTENS	Thousand Btu consumed / sq ft / year
ComSTEOBM	B-136	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 NEMS system parameter STEOBM.	Input from file KPARM	Unitless
CostTrendSwitch	B-55	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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
DatCtrShare	B-31	Service Demand	Share of large office floorspace representing data centers.	Calculated variable	Unitless
Dcf	B-32	Service Demand	Service demand intensity ratio of data centers to large office buildings by end-use service.	Parameter defined in source code	Unitless
DecAvgEff	B-89	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 delivered / thousand Btu consumed
DecayBM	B-137	Benchmarking	Flag to indicate whether optional benchmarking to STEO is to include taper of final mistie to zero. Value of one indicates yes; zero indicates no.	Input from file KPARM	Unitless
DecFuelShare	B-92	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-105	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 is available from 1990 through 2005. Data for 2006 is extrapolated using historical data through September. Data input for subsequent years is based on a 30-year average for heating and cooling degree days, adjusted for projected state population shifts. The data is used to perform a weather adjustment to the consumption projections in the Consumption subroutine, and to determine the relative amounts of heating and cooling supplied by heat pumps (Equation B-80).	Input from KDEGDAY	Degrees Fahrenheit $\times$ day

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
DistServBoilerEff	B-112	Consumption	Efficiency of conversion of fuel to steam energy by boilers used to provide district services, by fuel type.	Input from file KDSEFF	Btu out / Btu in
DistServConsump	B-112	Consumption	Consumption of fuels to provide district services, by Census division, building type, fuel, year, and district service.	Calculated	Trillion Btu in
DistServFuelShr	B-112	Consumption	Proportions of district service steam energy generated by each fuel type. Dimensions: building type and fuel.	Input from file KDSFS	Unitless
DistServSteamEUI	B-112	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
DRItoCBECS	B-4	Floorspace	Matrix of coefficients specifying the proportion of floorspace for each of the Dodge/DRI building types that is included in each of the CBECS building type floorspace totals.	Defined in source code	Unitless
EF1	B-103	Consumption	Weight given to ratio of current fuel price relative to CBECS year fuel price in calculating short-term price elasticity.	Defined in source code	Unitless
EF2	B-103	Consumption	Weight given to ratio of previous year fuel price relative to CBECS year fuel price in calculating short-term price elasticity.	Defined in source code	Unitless
EF3	B-103	Consumption	Weight given to ratio of fuel price from two years previous relative to CBECS year fuel price in calculating short-term price elasticity.	Defined in source code	Unitless
EffectHurdle	B-59	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-96	Technology Choice	Average annual growth rate of minor service efficiencies.	Module input from KDELEFF	Unitless

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
ElShr	B-107	Consumption	Share of electricity consumption by end-use. Used to compute adjustment to account for self-generation. Dimension: end-use service.	Computed	Unitless
EndUseConsump	B-101	Consumption	Projected consumption of fuel by end-use service, major fuel, building type, Census division, and projection year.	Calculated variable	Trillion Btu
EquipRestriction	B-14	Service Demand	A logical variable ("flag") indicating whether a given technology class and vintage is blocked from use in a given building type and Census division. A value of zero indicates the technology class and vintage is allowed; one indicates it is blocked or not allowed.	Input from file KTECH	Unitless
ExistImprov	B-23	Service Demand	Heating building shell efficiency improvement for existing buildings achieved by the year 2030 as a proportion relative to the CBECS base year (currently, 2003).	Input from file KSHEFF	Unitless
ExistShBaseStock	B-23	Service Demand	Base year to current year improvement in heating building shell efficiency for buildings surviving from the base-year floorstock.	Calculated variable	Unitless
FinalEndUseCon	B-116	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-137	Benchmarking	Final year of time span over which to taper down the final STEOMistie optionally used in benchmarking (currently 2008). If STEO benchmarking option is selected, and the STEO taper option is selected, then the adjustment for FirstNonBenchYr and future years due to mismatch with STEO during earlier years becomes zero.	Input from file KPARM (into temporary intermediate variable named LastDecayYr)	Calendar year
FS	B-84	Technology Choice	Fuel share of service by Census division, building type, end-use service, decision type, and major fuel.	Calculated variable	Unitless
FuelbyTech	B-17	Service Demand	A logical variable ("flag") indicating whether a given technology uses a given fuel, by technology class and fuel type.	Parameter	Unitless

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
FuelShareofService	B-86	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
Gamma	B-55	Technology Choice	Shape parameter corresponding to the rate of price decline in the cost trend function	Input from KTECH	Unitless
HeatPumpCoolingSD	B-81	Technology Choice	Amount of cooling service demand satisfied by heat pumps by decision type (new replacement, and retrofit).	Calculated variable	Trillion Btu out
Hurdle	B-58	Technology Choice	Hurdle (implicit discount) rate. The sum of the ten-year treasury bond rate and the risk-adjusted time preference premium for the current major service, risk-adjusted time preference level, and projection year.	Calculated variable	Unitless
HurdleElas	B-59	Technology Choice	Hurdle (implicit discount) rate elasticity parameter by Census division, service and fuel.	Input from file KHURELA	Unitless
IFMAX	B-139	Technology Choice	Maximum number of years a technology's availability can be advanced due to increased fuel prices under Price-Induced Technological Change.	Input from KPARM	Number of years
KElast	B-100	Consumption	Graduated short-term price elasticity function. Elasticity for a given major fuel, end-use service, and Census division in a given year is calculated as a weighted function of the price of the given fuel in the current year and the previous two years relative to the fuel price in CBECS year.	Calculated variable	Unitless

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
KEqCost	B-55	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 2004 dollars / (thousand Btu out per hour) / year Lighting: Constant 2004 dollars / thousand lumens / year Ventilation: Constant 2004 dollars / thousand CFM
Kscale	B-18	Service Demand	The scale factor, by fuel type, that is applied to KTECH market shares of service demand of equipment using a given 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 building type, and is necessary because the KTECH market shares are regional, and constant across building types, whereas the EUIs vary by building type.	Calculated variable	Unitless
KSTEOYR	B-125	Consumption	Index of last year of STEO data used for benchmarking. Currently 17, corresponding to 2006.	Parameter	Unitless
LCMSNR	B-65	Technology Choice	Equipment market shares of service within least cost behavior segment of new and replacement decision types, by technology class and model number (t,v).	Calculated variable	Unitless
LCMSRet	B-76	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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
MarketPenetration	B-37	Service Demand	Market penetration index by minor service and year for the three services: Office Equipment; PC, Office Equipment; NonPC, and Other End-Uses. Represents factor to be applied to base year saturation level to obtain current year projected saturation level.	Input from file KOFFPEN	Unitless
MC_COMMFLSP	B-4	Floorspace	NEMS Macro Module projection of total commercial floorspace, by Dodge/DRI building type, Census division, and projection year.	Input from NEMS Macroeconomic Activity Module	Billion square feet
MC_RMGBLUSREAL	B-58	Technology Choice	Yield on U.S. Government ten year bonds.	Input from NEMS Macroeconomic Activity Module	Percent
MinFuelBeta	B-121	Consumption	Elasticity parameter used in the calculation of minor fuel consumption.	Input from file KMINFL	Unitless
MiscElDmd	B-41	Service Demand	Service demand for a given specific category of miscellaneous electricity use in a given building type and Census division for the current projection year.	Calculated Variable	Trillion Btu
MiscK0	B-40	Service Demand	Constant term in equation describing projected service demand for a given specific category of miscellaneous electricity use.	Defined in source code	Billion Btu water services in Trillion Btu
MiscK1	B-40	Service Demand	Coefficient for first order term in equation describing projected service demand for a given specific category of miscellaneous electricity use.	Defined in source code	Billion Btu water services in Trillion Btu
MiscK2	B-40	Service Demand	Coefficient for second order term in equation describing projected service demand for a given specific category of miscellaneous electricity use.	Defined in source code	Billion Btu water services in Trillion Btu
MiscK3	B-40	Service Demand	Coefficient for third order term in equation describing projected service demand for a given specific category of miscellaneous electricity use.	Defined in source code	Billion Btu water services in Trillion Btu

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
MS	B-70	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
MSEDYR	B-126	Benchmarking	Index of the final year of available SEDS data. Currently 14, corresponding to 2003.	NEMS system parameter	Unitless index
NewImprv	B-28	Service Demand	Heating building shell efficiency improvement for new buildings achieved by the year 2030 as a proportion relative to the CBECS base year (currently, 2003).	Input from file KSHEFF	Unitless
NewServDmd	B-27	Service Demand	Service demand in new commercial floorspace by Census division, building type, end-use service, and year. Same as NSD.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM hours
NewShAdj	B-28	Service Demand	Base year to current year improvement in heating building shell efficiency for new construction.	Calculated variable	Unitless
Normalizer	B-82	Technology Choice	Market share adjustment factor for space cooling equipment other than heat pumps.	Calculated variable	Unitless
NonspecMiscShr	B-37	Service Demand	Proportion of base year "Other" electricity use that is not part of a specific category of miscellaneous electricity use for a given building type.	Input in FORTRAN Data Statement	Unitless
NSD	B-80	Technology Choice	Service demand in new commercial floorspace by Census division, building type, end-use service, and year. Same as NewServDmd.	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
NUGFromSEDS	B-128	Benchmarking	Amount of historical SEDS commercial consumption attributable to the power sector by fuel, Census division, and year. Used to account for definitional differences between data sources. Currently set to zero.	Input from KCALNUG	Trillion Btu
Pop	B-130	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
Pr	B-59	Technology Choice, Consumption	Commercial sector fuel prices, by fuel (major and minor), Census division, and projection year. Electricity prices are also by end-use service.	Input from appropriate NEMS supply sector modules.	Constant 1987 dollars per million Btu (converted to 2004 dollars per million Btu for technology choice calculations)
PrevYrAverageEfficiency	B-96	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-66	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-47	Service Demand	Proportion of a given service demand that was satisfied by equipment of a particular technology and vintage within a given Census division and building type during the previous year.	Calculated variable	Unitless
Price	B-98	Technology Choice	Commercial sector national fuel prices, by fuel (major), 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-98	Technology Choice	Comparison of three year average fuel price to baseyear fuel price, by fuel (major), and projection year. Used to determine price-induced technological change.	Calculated variable	Unitless

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
ReplacementFuelShareofService	B-53	Technology Choice	Fuel shares of that portion of service demand requiring replacement due to equipment failure, by fuel.	Calculated	Unitless
ReplacementProportion	B-49	Technology Choice	Portion of service demand requiring replacement due to equipment failure, by Census division, building type, and service.	Calculated	Unitless
ReplacementShareofService	B-52	Technology Choice	Failed equipment shares of that portion of service demand requiring replacement due to equipment failure, by technology class and vintage (model).	Calculated	Unitless
RetireServDmd	B-47	Service Demand	Service demand in surviving floorspace that becomes unsatisfied in the current projection year due to 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-72	Technology Choice	Cost of removing and disposing equipment of a given 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 KTECH	Unitless
RSD	B-80	Technology Choice	Service demand in surviving floorspace that becomes unsatisfied in the current projection year due to equipment failure, by Census division, building type, end-use service, and year. Same as RetireServDmd.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out Lighting: Billion lumen years out Ventilation: Trillion CFM hours
SD	B-80	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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
SEDSMistie	B-126	Benchmarking	Difference between historical data on fuel consumption derived from State Energy Data System (SEDS), and the CBECS-based Commercial Module projections, by fuel (major and minor) and Census division.	Calculated variable	Trillion Btu in
ServDmdExBldg	B-22	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-20	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, currently 2003) based on the base year Energy Use Intensities, equipment market shares, and other considerations. Identical to the base year EUIs in the case of minor services, because minor service equipment efficiencies are indexed to 1 for the base year.	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
ServDmdSurv	B-48	Service Demand	Service demand in existing (i.e., not newly-constructed during the given 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-34	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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
SFMSN	B-66	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-67	Technology Choice	Equipment market shares of service demand within the same fuel behavior segment of the replacement purchase decision type, by technology class and model number (t,v).	Calculated variable	Unitless
SFMSRet	B-77	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
ShellEffFactor	B-56	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, currently 2003). ShellEffFactor(2) is the shell efficiency factor of new construction relative to the existing stock in the base year.	Calculated variable	Unitless
ShellEffIndex	B-23	Service Demand	Heating building shell efficiency index by Census division and building type. For building type b and Census division r, ShellEffIndex(b,r,1) is the current year average heating shell efficiency index of the total surviving floorspace relative to that of the base year (CBECSyear, currently 2003). ShellEffIndex(b,r,2) is the heating shell efficiency index of new construction relative to the existing stock in the base year.	New Construction: Input from file KSHEFF Existing Buildings: Calculated variable	Unitless
Shiftyears	B-99	Technology Choice	Shiftyears(t,v) is the number of years to shift forward the availability of vintage v of technology class t due to Price-Induced Technologica Change as long as Shiftyears(t,v) is 1) less than or equal to the maximum allowable shift in availability and 2) greater than the previous year’s shift.	Calculated variable	Number of years

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
SolarRenewableContrib	B-45	Service Demand	The amount of service demand satisfied by solar energy, by Census division, solar service, and projection year.	Input from file KRENEW	Non-lighting: Trillion Btu out Lighting: Billion lumen years out
SSD	B-80	Service Demand	Service demand in existing (i.e., not newly-constructed during the given 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-136	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 system parameter	Unitless
STEOMistie	B-133	Benchmarking	Difference between short-term forecast of fuel consumption given by the Short Term Energy Outlook (STEO), and the CBECS-based Commercial Module projections after benchmarking to SEDS using SEDSMistie, by fuel (major and minor) and Census division.	Calculated variable	Trillion Btu in
STEOTieDecayFactor	B-137	Benchmarking	Factor optionally applied to final STEO mistie during subsequent years if optional STEO benchmarking and tapering (see DecayBM) have been selected.	Calculated variable	Unitless
STMSN	B-68	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-69	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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
STMSRet	B-78	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-78	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
SurvFloorTotal	B-3	Floorspace	Total surviving commercial floorspace by Census division, building type, and year.	Calculated variable	Million sq ft
SurvivingFuelShareofService	B-51	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-50	Technology Choice	Equipment market shares of surviving service demand after adjustment for equipment failure, by Census division, building type, major service, equipment class, and equipment vintage (model).	Calculated	Unitless
TechAvailability	B-14	Technology Choice	Year boundaries of availability of equipment for purchase. For technology class t and vintage (model) v, TechAvailability(t,v,1) is the calendar year during which the equipment is first available for purchase in the model. TechAvailability(t,v,2) is the last year of equipment availability for purchase. By technology class and vintage (model).	Input from KTECH	Calendar year
TechbyService	B-47	Technology Choice	Logical “flag” variable constructed for use in determining which technology classes are defined for a given end-use service, by technology class and end-use service.	Calculated variable (based on KTECH input)	Unitless

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
TechCost	B-54	Technology Choice	Initial Equipment cost components by technology class and vintage. For technology class t and vintage v, TechCost (t,v,1) is the unit installed capital cost of the equipment. TechCost (t,v,2) is the annual operating and maintenance cost per unit service demand, not including fuel costs.	Input from KTECH	Non-lighting, non-ventilation: Constant 2004 dollars / (thousand Btu out per hour) / year Lighting: Constant 2004 dollars / thousand lumens / year Ventilation: Constant 2004 dollars / thousand CFM
TechCRI	B-60		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, 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 KTECH	Unitless
TechEff	B-17	Technology Choice	Efficiencies of specific equipment, with 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 KTECH	Non-lighting, non-ventilation: Btu delivered / Btu consumed (≡Btu out / Btu in) Lighting: lumens / watt Ventilation: thousand CFM-hrs air delivered / thousand Btu consumed
TechLife	B-47	Technology Choice	Median life expectancy of equipment, in years, by technology class and vintage (model).	Input from KTECH	Years; Unitless where used as exponent

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
TechShareofService	B-87	Technology Choice	Proportion of a given service demand that is satisfied by equipment of a particular technology and vintage within a given 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-15	Service Demand	Proportion of a given service demand that was satisfied by equipment of a particular technology and vintage within a given Census division and building type during the base year (CBECSyear, currently 2003). Calculated based on KTECH market shares, building restrictions, base year EUIs, and other considerations.	Calculated variable	Unitless
TimePrefPrem	B-58	Technology Choice	Consumer risk-adjusted time preference interest rate premium which 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-65	Technology Choice	Proportion of consumers who fall into given categories of consumer risk-adjusted time preference levels (implicit discount rates). The risk-adjusted time preference premiums applicable to each level are given by TimePrefPrem.	Input from file KPREM	Unitless
TotExplicitMiscElDmd	B-42	Service Demand	Total service demand for all specific categories of miscellaneous electricity use in a given building type and Census division for the current projection year.	Calculated Variable	Trillion Btu
TotMiscFloorspace	B-39	Service Demand	Total U.S. floorspace with demand for the type of services in a given specific category of miscellaneous electricity use for the current projection year.	Calculated Variable	Million sq ft
TotNewFS	B-24	Service Demand	Total of new construction from base to year before current year for given 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

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
TranFromSEDS	B-128	Benchmarking	Amount of historical SEDS commercial consumption attributable to the transportation sector by fuel, Census division, and year. Used to account for definitional differences between data sources. Currently set to zero.	Input from KCALTRN	Trillion Btu
UnBenchCon	B-117	Consumption	Unbenchmarked fuel consumption by fuel type, Census division, building type, and year.	Calculated variable	Trillion Btu
USMiscElDmd	B-40	Service Demand	Total U.S. service demand for a given specific category of miscellaneous electricity use in a given projection year.	Calculated variable	Trillion Btu
WaterSvcElQ	B-130	Benchmarking	Projected electricity consumption for municipal water services in a given Census division for the current projection year.	Calculated Variable	Trillion Btu
WaterSvcQGrowth	B-131	Benchmarking	Projected growth in electricity consumption for municipal water services from last year of available SEDS data to current projection year in a given Census division.	Calculated Variable	Trillion Btu
Xprice	B-61	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 2004 dollars per million Btu for technology choice calculations)
YearsForward	B-100	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
AccelFac	B-149	Distributed Generation	Indicator for allowed depreciation method. Straight line=100; 150% declining balance=150; double-declining balance=200. Dimensions: technology.	Input from file KGENTK	Unitless
AdjCost	B-140	Distributed Generation	Adjusted capital cost of equipment per kW for emerging technologies subject to learning. Dimensions: technology.	Computed	2005 dollars/kW
alpha	B-169	Distributed Generation	Parameter controlling shape of the logistic penetration function. Dimension: technology.	Input from file KGENTK	Unitless

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
AnnualKWH	B-151	Distributed Generation	Represents annual system kWh generation for the specific technology and vintage being analyzed.	Computed	KWh
Avail	B-143	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	Percentage
AvgKwh	B-162	Distributed Generation	Average annual electricity usage in kWh from CBECS estimated for a building with average floorspace within the building size category. Dimension: building type, building size category.	Input in FORTRAN Data Statement	KWh per year
BaseYrFuelCost	B-159	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	2005 Dollars
Basis	B-149	Distributed Generation	Portion of generating technology installed capital cost still to be depreciated.	Calculated Variable	Nominal Dollars
beta	B-140	Distributed Generation	Parameter controlling shape of the technology learning function. Dimension: technology.	Input from file KGENTK	Unitless
BldShr	B-170	Distributed Generation	Percentage used to distribute exogenous penetrations across building types. Dimension: building type, technology.	Input from file KGENTK	Percentage
BTUWasteHeat	B-156	Distributed Generation	Computed waste heat available for water and space heating (valid only for fuel-consuming generating technologies, currently excludes photovoltaics)	Computed	MMBtu
C0	B-140	Distributed Generation	"First of a kind" capital cost for a distributed generation technology.	Input from KGENTK	2005 Dollars
CapCost	B-140	Distributed Generation	Capital cost of equipment per kw. Dimensions: technology and vintage. May be adjusted based on technology learning.	Input from file KGENTK	2005 dollars/kW
CogHistYear	B-169	Distributed Generation	Index of the final year of available historical non-utility generation data. Currently 16, corresponding to 2005.	Parameter	Unitless index

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
CumCashFlow	--	Distributed Generation	Accumulated sum of all prior NetCashFlow amounts.	Computed	Nominal Dollars
Degredation	B-154	Distributed Generation	Degradation of conversion efficiency of technology. Currently applies to photovoltaics at a loss of 1 percent of total output per year. That is after 20 years, a 5 kw system would produce only 80 percent (1-20*1%) of its rated output or 4 kw. Dimensions: technology and vintage.	Input from file KGENTK	
DeltaPen	B-170	Distributed Generation	Computed penetration into the existing stock of floorspace.	Computed	Percentage
Depr	B-145	Distributed Generation	Computed depreciation amount based on straight-line or accelerated declining balance. Method depends on technology and AccelFac. Dimension: year.	Computed	Nominal Dollars
DownPay	B-142	Distributed Generation	The down payment percentage times the total installed cost for the specific technology and vintage being analyzed	Computed	2005 Dollars
DownPayPct	B-142	Distributed Generation	Down payment percentage assumed to apply to loans for distributed generation investment	Input from file KGENTK	Percentage
ElEff	B-151	Distributed Generation	Electrical conversion efficiency. Dimensions: technology and vintage.	Input from file KGENTK	Percentage
ElShr	B-107	Consumption	Share of electricity consumption by end-use. Used to compute adjustment to account for self-generation. Dimension: end-use service.	Computed	Unitless
EqCost	B-141	Distributed Generation	Sum of installation cost per kw plus capital cost per kw multiplied by total system kw. May be adjusted based on learning effects.	Computed	2005 Dollars
eqlife	--	Distributed Generation	Useful life of equipment. Dimensions: technology and vintage.	Input from file KGENTK	Years
equipname	--	Distributed Generation	Name for reporting purposes. Dimensions: technology.	Input from file KGENTK	Character data
ExogPen	B-170	Distributed Generation	Program-driven cumulative units. Dimensions: Census division, technology, year.	Input from file KGENTK	Number of units

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
FuelCost	B-160	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-155	Distributed Generation	MMBtu of fuel input by the technology.	Computed	MMBtu
FuelUsage	B-111, B-173	Consumption, Distributed Generation	Accumulated total fuel consumption (if applicable) for all distributed generators. Dimension: year, Census division, building type, technology.	Computed	Trillions of Btu
HWBtu	B-110, B-174	Consumption, Distributed Generation	Accumulated total water heating Btus provided by distributed resources. Dimension: year, Census division, building type, technology	Computed	Trillions of Btu
ifirstyr	--	Distributed Generation	First year a technology is available. Dimensions: technology and vintage.	Input from file KGENTK	Year
ifueltype	--	Distributed Generation	Fuel type indicator for mapping technologies to fuels and fuel prices. Dimensions: technology.	Input from file KGENTK	Integer pointer
ilastyr	--	Distributed Generation	Last year a technology is available. Dimensions: technology and vintage.	Input from file KGENTK	Year
inflation	B-160	Distributed Generation	Inflation assumption for converting constant dollar fuel costs and fuel cost savings into current dollars for the cashflow model in order to make the flows correspond to the nominal dollar loan payments.	Input from file KGENTK	Percentage
InstCost	B-141	Distributed Generation	Installation cost per kw. Dimensions: technology and vintage.	Input from file KGENTK	2005 dollars/kW
IntAmt	B-145	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-164	Distributed Generation	Maintenance cost for 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	2005 dollars/kW

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
IntRate	B-143	Distributed Generation	Commercial mortgage rate.	Input from file KGENTK	Percentage
Invest	B-176	Distributed Generation	Current year investment in distributed resources. Dimension: year, Census division, building type, technology.	Computed	Millions of 2005 Dollars
kW	B-141	Distributed Generation	System peak capacity. Dimensions: technology and vintage.	Input from file KGENTK	kW
KWH	B-154	Distributed Generation	kWh generated in each of the years of the cashflow analysis. Defined as annual kWh adjusted for degradation (i.e., if degradation factor is not equal to zero).	Computed	kWh
LoanBal	B-145	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-151	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	Percentage
MaintCost	B-164	Distributed Generation	The maintenance cost from the input file (for the specific technology and vintage being analyzed), inflated to current year dollars for the cashflow analysis. Includes inverter replacement at discrete intervals for PV systems. Dimension: year.	Computed	Nominal Dollars
MaintCostBase	B-164	Distributed Generation	Annual maintenance cost per kw. Dimensions: technology and year.	Input from file KGENTK	2005 dollars/kW
MaxPen	B-168	Distributed Generation	Computed maximum penetration into new construction.	Computed	Percentage
ModuleSqft	B-151	Distributed Generation	Estimated PV array square footage for a 1-kw system.	Computed	Square Feet
NetCashFlow	B-166	Distributed Generation	Net of costs and returns for the specific technology and vintage being analyzed in the cashflow analysis. Dimension: year.	Computed	Nominal Dollars

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
netmeteradj	--	Distributed Generation	Currently disabled. A percentage scalar that applies to the retail rate of electricity for sales to the grid (i.e., reverse flows of energy into the grid). Currently replaced with a grid sales price provided by the NEMS Electric Market Module. Dimensions: technology and Census division.	Input from file KGENTK	Percentage
OperHours	B-153	Distributed Generation	Operation hours. Dimensions: technology.	Input from file KGENTK	Hours
Outlay	B-144	Distributed Generation	Outlays for capital relating to down payments and borrowing costs.	Calculated	2005 Dollars
Payment	B-143	Distributed Generation	Computed annual payment using loan amortization formula	Calculated	2005 Dollars
PelCMout	B-161	Distributed Generation	Commercial sector electricity prices. Dimensions: Census division, projection year, end-use service.	Input from NEMS Electricity Market Module	Converted to 2005 dollars per million Btu for cash flow calculations
PelME	B-162	Distributed Generation	Marginal price for utility purchases. Used for calculating the value of electricity sold to the grid. Dimensions: Census division, projection year.	Input from NEMS Electricity Market Module	Converted to 2005 dollars per million Btu for cash flow calculations
Pen	B-169	Distributed Generation	Computed penetration into new construction.	Computed	Percentage
PenParm	B-168	Distributed Generation	Parameter controlling maximum penetration into new construction. Dimension: technology.	Input from file KGENTK	Unitless
Prin	B-145	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
SHBtu	B-110, B-175	Consumption, Distributed Generation	Accumulated total space heating Btus provided by distributed resources. Dimension: year, Census division, building type, technology.	Computed	Trillions of Btu
SimplePayback	B-167	Distributed Generation	The year number of the first year in the cashflow stream for which an investment has a positive cumulative net cashflow.	Computed	Year Index

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
SolarIns	B-151	Distributed Generation	Solar insolation for photovoltaics. Dimensions: Census division.	Input from file KGENTK	kWh per square foot per year
SpaceHeatingMMBtu	B-158	Distributed Generation	Waste heat available to serve space heating requirements. Nonzero only if total available Btu of waste heat is greater than water heating requirements.	Computed	MMBtu per year
TaxCredit	B-147	Distributed Generation	Allowed tax credit computed as the maximum of TxCreditMax and the TaxCreditPct times the total installed cost. Dimension: year.	Computed	Nominal Dollars
TaxCreditPct	B-147	Distributed Generation	Percentage applied to installed cost for computing tax credit.	Input from file KGENTK	Percentage
TaxDeduct	B-165	Distributed Generation	Combined tax rate times interest paid in the previous year plus any applicable tax credit. Dimension: year.	Computed	Nominal Dollars
TaxLife	B-148	Distributed Generation	Tax life of equipment, generally different from useful life. Dimensions: technology and vintage.	Input from file KGENTK	Years
TaxRate	B-165	Distributed Generation	Marginal combined federal and state income tax rate, currently assumed to be 40% for the typical commercial business	Input from file KGENTK	Percentage
Term	B-143	Distributed Generation	Commercial loan term	Input from file KGENTK	Years
Trills	B-108, B-171	Consumption, Distributed Generation	Accumulated total electric generation by all distributed generators. Dimension: year, Census division, building type, technology.	Computed	Trillions of Btu
TrillsOwnUse	B-172	Distributed Generation	Accumulated total electric generation retained for own use on-site. Dimension: year, Census division, building type, technology.	Computed	Trillions of Btu
TxCreditMax	B-147	Distributed Generation	Cap on the total dollar amount of a tax credit (if any). Dimensions: technology and vintage.	Input from file KGENTK	2005 dollars
Units	B-170	Distributed Generation	Total number of units with distributed generation installed. Dimension: year, Census division, building type, technology.	Computed	Number of Units

Input/Output Name	Equation Number	Subroutine	Definition and Dimensions	Classification	Units
ValElecSave	B-163	Distributed Generation	Inflated base year value of energy savings in nominal dollars for the cashflow analysis. Dimension: year.	Computed	Nominal Dollars
ValElecSaveBase	B-161	Distributed Generation	Initial value of generated electricity savings to begin the cashflow model net benefits calculation.	Computed	2005 Dollars
WaterHeatingMMBtu	B-157	Distributed Generation	The lesser of: 1) average annual water heating required for average size building in given 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, size category.	Computed	MMBtu per year
WhRecoveryEff	B-156	Distributed Generation	Waste heat recovery factor for technologies that burn fuel (i.e., not photovoltaics). This waste heat can then be made available for water and space heating which provides additional energy cost savings for distributed generation technologies. Dimensions: technology and vintage.	Input from file KGENTK	Percentage

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: PCS proportion of base year office equipment EUI

CLASSIFICATION: Input parameter (KPARM)

DISCUSSION:

The 2003 Commercial Buildings Energy Consumption Survey (CBECS) provides data on energy consumption by building, and includes data on the number of PCS present in each building surveyed. However, the 2003 CBECS EUIs were not available for *AEO2007*. The 1995 CBECS provides CBECS-derived estimates of the end-use intensities (EUIs) by building type, fuel type, and Census division for the end-use services modeled by the NEMS Commercial Sector Demand Module, by a combination of engineering simulation and Conditional Demand Analysis approaches. This results in estimates for the office equipment EUIs, but without a separate breakout into personal computers (PCS) and other office equipment.

A representative national estimate of the 2003 proportion of office equipment EUI attributable to PC use has been developed by EIA analysts, based on the CBECS data and studies referenced below. Because this estimate is based partly on expert judgement, it is placed in the Commercial Module parameter file, KPARM, where it can be easily updated by other specialists. There is also a mechanism for automatically disabling its use should specific PC EUIs be developed and placed in the EUI input file, KINTENS.

SOURCES:

J. G. Koomey, M. Cramer, M. Piette, and J. H. Eto. *Efficiency Improvements in U. S. Office Equipment: Expected Policy Impacts and Uncertainties*. Lawrence Berkeley Laboratory, December, 1995, LBL-37383.

Original work by Eugene Burns and Kristine McSkimming of the U.S. Department of Energy, Energy Information Administration.

Energy Information Administration. *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*. Washington DC, October 1998, DOE/EIA-0625(95), GPO Stock No. 061-003-01046-6.

Energy Information Administration. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site www.eia.doe.gov/emeu/cbecs/.

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 judgement 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 judgement 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 *A Look at Commercial Buildings 1995: Characteristics, Energy Consumption, and Energy Expenditures* and from the 1999 Commercial Buildings Energy Consumption Survey public use files are utilized to weight these estimates by building type to yield replacement and retrofit behavior rule proportions by building type. The complete data set for the 2003 CBECS was not available in time to update the analysis of building ownership patterns for *AEO2007.* The 2003 building ownership patterns will be incorporated into the behavior rule assumptions for *AEO2008.* Similarly, judgement estimates are made for self-built and speculative developer floorspace for the new decision type. These 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 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.

Energy Information Administration. *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*. Washington DC, October 1998, DOE/EIA-0625(95), GPO Stock No. 061-003-01046-6

Energy Information Administration. 1999 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, October 2002, web site www.eia.doe.gov/emeu/cbecs/1999publicuse/99microdat.html.

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.

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.

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

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.

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.

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.

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 equipment were run 100% of the time at full capacity. Space conditioning capacity factors are developed by Census division, service, and building type from the ratio of average daily load to peak load for space heating and space cooling at 44 selected cities in the EPRI source cited below. The averages for the cities in each Census division are weighted by population to compute the capacity factors used by the NEMS Commercial Sector Demand Module. Lighting capacity factors vary by building type and are based upon the ratio of average hours of operation to total hours from *Lighting in Commercial Buildings*. 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 in the EPRI source.

SOURCES:

Decision Focus, Inc. *TAG Technical Assessment Guide, Vol. 2: Electricity End Use; Part 2: Commercial Electricity Use -- 1988*. Palo Alto CA, Electric Power Research Institute, October 1988, pp. 4-5 to 4-29, 9-10 to 9-27.

Energy Information Administration. *Energy Consumption Series: Lighting in Commercial Buildings*. DOE/EIA-0555(92)/1. Washington DC, March 1992. p. 38.

MODEL INPUT: Base year commercial floorspace

VARIABLE NAME: CBECSFlrSpc

MODEL COMPONENT: Floorspace

DEFINITION: Commercial floorspace by building type *b* in Census division *r* for 2003

CLASSIFICATION: Input from file KFLSPC

DISCUSSION:

A straightforward aggregation of weighted survey data from the 2003 CBECS was used to compute 2003 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 Commercial Sector Demand Module is shown in the table below:

NEMS Classification Plan for Building Types:

NEMS	2003 CBECS
Assembly	Public Assembly Religious Worship
Education	Education
Food Sales	Food Sales
Food Services	Food Services
Health Care	Health Care - Inpatient
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:

Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, web site http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

Energy Information Administration. Description of CBECS Building Types. Web site http://www.eia.doe.gov/emeu/cbecs/building_types.html.

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 Commercial Sector Demand Module. Insufficient data addressing median expected commercial building usage lifetimes were available to enable disaggregation to the Census division level; consequently, a characterization at the national level was developed 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.

Electric Power Research Institute. *Commercial End-Use Data Development Handbook: COMMEND Market Profiles and Parameters, Vol. 2: COMMEND Data and Parameter Development Techniques*. Regional Economic Research, Inc. San Diego, California. EM5703, April 1988, p. 2.24.

Energy Information Administration. 1999 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, October 2002, web site www.eia.doe.gov/emeu/cbecs/1999publicuse/99microdat.html.

Energy Information Administration. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site www.eia.doe.gov/emeu/cbecs/.

Energy Information Administration. 1992 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, July 1996, web site www.eia.doe.gov/emeu/cbecs/.

Energy Information Administration. 1989 Commercial Buildings Energy Consumption Survey, Microdata. Washington DC, April 1992,

Energy Information Administration. *Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings 1986*, Washington DC, September 1988,

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

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 2005; Input from file KCOGEN prior to 2006

DISCUSSION:

Historical data for commercial sector North American Industry Classification System (NAICS) codes from the EI-860: Annual Electric Generator Report for the years 2004 through 2005 forms the basis for projected power generation by CHP plants by fuel and Census division. The EI-860 surveys generating facilities of 5 MW or more, and with 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 exhaustive.

For years after 2005, 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:

Energy Information Administration. Form EI-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 Commercial Sector Demand Module models floorspace retirement using the logistic survival function,

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

It can be seen that 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 the text of the Commercial Model Documentation 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.

SOURCES:

Energy Information Administration. 1999 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, October 2002, web site www.eia.doe.gov/emeu/cbecs/1999publicuse/99microdat.html.

Energy Information Administration. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site www.eia.doe.gov/emeu/cbecs/.

Energy Information Administration. 1992 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, July 1996, web site www.eia.doe.gov/emeu/cbecs/.

Energy Information Administration. 1989 Commercial Buildings Energy Consumption Survey, Microdata. Washington DC, April 1992,

Energy Information Administration. *Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings 1986*, Washington DC, 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:

The 2003 CBECS building characteristics include the year of building construction. Nine age categories, referred to as "vintage cohorts" are used by CBECS and the NEMS Commercial Sector Demand Module 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-1900) was determined to be 1825 during processing of the CBECS data set, and is the value currently assigned to the input parameter, CMOldestBldgVint.

SOURCES:

Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, web site http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

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 National Energy Modeling System (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 SEDS data is provided to the NEMS Commercial Sector Demand Module by the NEMS Integrating Module, and is more fully described in the Integrating Module Documentation Report. Currently, the latest year for which SEDS data is supplied is 2003. This data is supplemented with data from the *Annual Energy Review 2005* (AER) for 2005 and projections from the Short Term Energy Outlook (STEO) for the commercial sector for the years 2006 – 2007. Data from the AER for 2005 are treated by the Commercial Module as if it were SEDS data, which is very likely to become the actual case. STEO data for 2006 and 2007 are available for optional benchmarking during those years, at the user's discretion. For *AEO2007*, the NEMS Commercial Module benchmarks to STEO data through the year 2006.

SOURCES:

Energy Information Administration. State Energy Consumption, Price, and Expenditure Estimates (SEDS). Washington DC, web site: http://www.eia.doe.gov/emeu/states/_seds.html

Energy Information Administration. *Annual Energy Review 2005*. DOE/EIA-0384(2005). Washington DC, July 2006.

MODEL INPUT: Floorspace vintages

VARIABLE NAME: CMVintage

MODEL COMPONENT: Floorspace

DEFINITION: Median year of construction of commercial floorspace existing in 1999, by building type, Census division, and vintage cohort group.

CLASSIFICATION: Input from file KVINT

DISCUSSION:

The 2003 CBECS data set 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-1900

1900 - 1919

1920 - 1945

1946 - 1959

1960 - 1969

1970 - 1979

1980 - 1989

1990 - 1999

2000 – 2003

The results vary with building type and Census division, and are organized for input to the Commercial Module in the KVINT file.

SOURCES:

Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, web site http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

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*, 1000 Btu consumed/ft^2.

CLASSIFICATION: Input from file KINTENS

DISCUSSION:

Energy end-use intensity estimates for the 2003 CBECS were not available for *AEO2007*. However, the CBECS 1995 Public Use Data provides CBECS-derived estimates of the end-use intensities (EUIs) by building type, fuel type, and Census division for the end-use services modeled by the NEMS Commercial Sector Demand Module, by a combination of engineering simulation and Conditional Demand Analysis approaches. These EUI estimates were subjected to a smoothing procedure and adjusted to CBECS 2003 building-level consumption estimates. The results were then adjusted to account for equipment replacement, new construction, changes in operating hours, and weather differences between 1995 and 2003. The final adjusted EUI estimates are input to the Commercial Module from the KINTENS input file.

SOURCES:

Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, web site http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

Energy Information Administration. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site www.eia.doe.gov/emeu/cbecs/.

Original work by Eugene Burns of the U.S. Department of Energy, Energy Information Administration.

Preliminary 1999 building-level energy consumption data received August 2002 from the Office of Energy Markets and End Use of the Energy Information Administration.

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 and DegreeDays (2,r,y) is the number of cooling degree days in Census division r during year y. Historical Data is available from 1990 through 2005. Data for 2006 is extrapolated using historical data through September. Data input for subsequent years is based on a 30-year average for heating and cooling degree days, adjusted for projected state population shifts. The data is 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 (2003) 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 5-2*, September 1995.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, population weighted heating and cooling degree days from web site: nic.fb4.noaa.gov/products/analysis_monitoring/cdus/.

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 KTECH

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 cost trend function is currently only employed for lighting technologies. The assumed values are included in the Technology Characterization Menu of the NEMS Commercial Module. These input parameters are based on the Decision Analysis Corporation source cited below, modified to reflect historical trends found in the Office of Research and Standards source.

SOURCES:

Decision Analysis Corporation of Virginia, *Lighting System Technology Characterization for the NEMS Commercial Sector Demand Module*, prepared for Energy Information Administration, Contract No. DE-AC01-92EI21946, August 1996.

U.S. Department of Energy, Office of Research and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Fluorescent Lamp Ballast Proposed Rule*, Washington DC, January 2000.

MODEL INPUT: District service boiler efficiencies

VARIABLE NAME: DistServBoilerEff

MODEL COMPONENT: Service Demand

DEFINITION: Efficiency of conversion of fuel to steam energy by boilers used to provide district services

CLASSIFICATION: Input from file KDSEFF

DISCUSSION:

National average values for typical boiler efficiencies in converting the fuels of electricity, natural gas, and distillate oil to the intermediate products of steam, hot water, and chilled water, were estimated from tabular data presented in the *1992 National Census of District Heating, Cooling, and Cogeneration*.

SOURCES:

U. S. Department of Energy. *1992 National Census of District Heating, Cooling, and Cogeneration*. Prepared by BMS Management services for U. S. Department of Energy, July, 1993.

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 *Assessment of Energy Consumption in Multifacility Buildings* report and the *1992 National Census of District Heating, Cooling, and Cogeneration*. The fuel share estimates are input to the NEMS Commercial Sector Demand Module from the file KDSFS, by fuel and building type.

SOURCES:

U. S. Department of Energy. *1992 National Census of District Heating, Cooling, and Cogeneration*. Prepared by BMS Management services for U. S. Department of Energy, July, 1993.

Energy Information Administration. *Energy Consumption Series: Assessment of Energy Use in Multibuilding Facilities*. DOE/EIA-0555(93)/1. August 1993.

MODEL INPUT: District service steam EUIs

VARIABLE NAME: DistServSteamEUI

MODEL COMPONENT: Service Demand

DEFINITION: Steam energy per square foot (MBtu/sqft) 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:

Steam energy EUI estimates were developed using the 1995 CBECS data set in a manner similar to the development of EUI estimates for other end uses. The steam EUI values are totals by building type and Census division, and are not broken down by generating fuel. Energy end-use intensity estimates for 2003 CBECS are not available. The CBECS 1995 steam energy EUI estimates will be used until new CBECS steam EUI estimates become available.

SOURCES:

Energy Information Administration. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site www.eia.doe.gov/emeu/cbecs/.

Original work by Eugene Burns of the U.S. Department of Energy, Energy Information Administration.

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: NonPCs, and miscellaneous ("other") services.

CLASSIFICATION: Input from file KDELEFF

DISCUSSION:

Optional efficiency improvement factors for any of the minor services may be provided by the user. The annual improvement factor is obtained by calculating the annual percentage improvement in the equipment stock that must be attained in order to reach the target energy efficiency improvement for the entire stock by 2030. Changes in energy consumption for PCs, NonPC Office Equipment and specific categories within miscellaneous services are now explicitly accounted for in the projections described under Market Penetration. Efficiency improvement for the non-specific portions of miscellaneous services is set to zero due to lack of information. Thus the entries in KDELEFF are set to zero for *AEO2007*.

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.

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 (2003) fuel price. The parameter is based on user input and allowed to vary by Census division, end-use service and major fuel. Current parameter values are based on analyst judgement.

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 (2003) fuel price. The parameter is based on user input. Current parameter values are based on analyst judgement.

MODEL INPUT: Office equipment penetration

VARIABLE NAME: MarketPenetration

MODEL COMPONENT: Service Demand

DEFINITION: Office Equipment (PC, nonPC) and "Other" market penetration index by building type and year

CLASSIFICATION: Input from file KOFFPEN

DISCUSSION:

The energy consumption projections for PC-related equipment (computers, monitors and printers) are based on information from a variety of sources. Base year information on the number of PCs is from EIA's 2003 CBECS. Current specifications and requirements for Energy Star office equipment are taken from the EPA Energy Star website (www.energystar.gov). Data for energy consumption by PC CPUs and monitors for Energy Star and non-Energy Star equipment are from communications with EPA and supported by LBNL and ADL studies on utilization and energy consumption (Kawamoto, et.al., Roberson, et.al., ADL January 2002). Projections of the total number of PCs in service are based on shipments from *Appliance Magazine* and an assumed further penetration. Adjustments to projected PC energy consumption for the increasing penetration of liquid crystal flat panel monitors are also made. The same sources provide energy consumption and sales forecast information regarding non-PC office equipment and IT-related "other" equipment. The market penetration index is set to unity in 2003, and increases based on projected consumption. The indexed projections of office equipment market penetration are included in the NEMS Commercial Module calculation of service demand. MarketPenetration for "Other" applies only to the non-specific portions of miscellaneous services.

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.

Dana Chase Publications, "52nd Annual Statistical Review," *Appliance Magazine*, May 2005, page S-4.

Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, website http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

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.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, Reference No. 117934, prepared for U.S. Department of Energy, Energy Information Administration, September 2004.

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.

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

MODEL INPUT: Minor fuel consumption elasticity parameter

VARIABLE NAMES: MinFuelBeta

MODEL COMPONENT: Consumption

DEFINITION: Elasticity parameter used in the calculation of minor fuel consumption

CLASSIFICATION: Input from file KMINFL

DISCUSSION:

MinFuelBeta is used as follows:

$$FinalEndUseCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y} \cdot Price_{f,r,y}^{MinFuelBeta_{r,f-CMnumMajFl}}$$

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

where FinalEndUseCon is final end-use minor fuel consumption. Minor fuel final end-use consumption is measured in trillion Btu in for $f \in$ {residual fuel oil, LPG, coal, motor gasoline, kerosene} for Census division r for year y, and is calculated for all projection years using a six-year moving average of previous years' consumption. The moving average is modified by the expression above and adjusted for sector growth. MinFuelBeta is calculated using the historical data on minor fuel consumption and prices from 1970-1992 provided by SEDS publications.

SOURCES:

Energy Information Administration. *State Energy Data Report: Consumption Estimates, 1960-1990*, DOE/EIA-0214(90), Washington DC, May 1992.

Energy Information Administration. *State Energy Price and Expenditure Data System (SEPEDS) Database, 1970-1991*.

Energy Information Administration. *State Energy Data Report 1992: Consumption Estimates*, DOE/EIA-0214(92), Washington DC, May 1994.

MODEL INPUT: Specific miscellaneous use category equation coefficients

VARIABLE NAME: MiscK0, MiscK1, MiscK2, MiscK3

MODEL COMPONENT: Service Demand, Benchmarking for municipal water services

DEFINITION: Equation coefficients defining projected consumption trends in specific miscellaneous electricity use categories within in "Other".

CLASSIFICATION: Provided with associated equations in Subroutines COMServiceDemand and COMBenchmarking as appropriate

DISCUSSION:

Projected service demands projections for specific miscellaneous electricity use categories within "Other" end-use services are based on electricity consumption estimates and projected national-level trends from a September 2006 study completed by TIAX LLC. Polynomial equations 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 municipal water services is included in the calculation of non-building energy consumption in the Benchmarking subroutine and is dependant on projected population growth instead of floorspace. The coefficients for the polynomial equations are in units of billion Btus (trillion Btus for municipal water services) and are provided in Table A-2.

Table A-2. Miscellaneous Electricity Use Category Equation Coefficients

Category Index (mc)	Electricity Use	Equation Coefficients			
		MiscK0	MiscK1	MiscK2	MiscK3
1	Coffee Brewers	598.8	0.2	0.048	-0.002
2	Distribution Transformers: Dry-type	1593.3	-19.55	-0.637	0.02
3	Distribution Transformers: Liquid	127.4	-0.6	0.03	-0.0006
4	Non-road Electric Vehicles	414.0	5.345	-0.0395	0
5	MRIs	676.0	136.0	4.0	-0.124
6	CT Scanners	1240.5	158.4	-4.57	0.04
7	X-ray Machines	6353.0	216.4	11.0	-0.37
8	Elevators	207.2	-1.63	0.026	0.0
9	Escalators	34.39	-0.05	0.0063	-0.00017
10	Municipal Water Services	206.36	2.85	0.085	0.0016

SOURCES:

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

MODEL INPUT: Retrofit removal and disposal cost

VARIABLE NAME: RetroCostFract

MODEL COMPONENT: Technology Choice

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

CLASSIFICATION: Input from KTECH

DISCUSSION:

The cost is expressed as a proportion to be applied to the installed capital cost. Currently, a placeholder value of 0.0 is used throughout the Commercial Sector Demand Module, pending acquisition and analysis of appropriate data.

SOURCES:

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 undertaken to determine whether significant variations existed by building age in the proportions of floorspace receiving various end use services found, for several services, a measurable difference between the two broad classes of ‘old’ and ‘new.’ For this characterization, ‘new’ was defined as floorspace constructed after 1989. The NEMS Commercial Sector Demand Module parameters characterizing service demand patterns are derived by considering the entire floorspace stock as sampled by CBECS 92, and are influenced most heavily by values corresponding to the ‘old’ floorspace category. In order 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 survey records.

SOURCES:

U.S. Department of Energy, Energy Information Administration, 1992 Commercial Buildings Energy Consumption Survey, Public Use Data Diskettes.

MODEL INPUT: Building shell efficiency index

VARIABLE NAME: ShellEffIndex

MODEL COMPONENT: Service Demand

DEFINITION: Shell efficiency index 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 2003 existing stock shell efficiency is indexed to 1.0 for each building type. The building shell efficiency index measures the improvement in the shell integrity of newly-constructed floorspace that must by law adhere to building codes, and the general improvement in overall existing stock shell efficiency that results from the continual introduction of more shell-efficient new construction.

Regional shell efficiency parameters developed from a 1998 Arthur D. Little (ADL) study cited below are included in the model. The ADL study is based on prototypical building characteristics developed by LBNL from 1989 CBECS data with additional values estimated by ADL. The ADL study analyzes the impacts on shell efficiency based upon three groups of buildings: existing buildings built during or before 1980, those built between 1980 and 1989, and those built in accordance with ASHRAE 90.1-1989 performance criteria. Regional data from the ADL study enables regional variation to be included in the model. Data from the 1999 CBECS were used to adjust the indices for new construction between 1990 and 1999. The parameters will be adjusted to account for new construction between 2000 and 2003 for *AEO2008*.

SOURCES:

ASHRAE, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., ASHRAE/IES 90.1-1989, Atlanta, GA, 1989.

Decision Analysis Corporation & Arthur D. Little, Inc., "Determination of Typical Commercial Building Shell U-Values", Draft report prepared under contract DE-AC01-98EI34585.

Energy Information Administration. 1999 Commercial Buildings Energy Consumption Survey, Public Use Files. Washington DC, October 2002, web site www.eia.doe.gov/emeu/cbecs/1999publicuse/99microdat.html.

Energy Information Administration, *Commercial Buildings Characteristics 1989*, DOE/EIA-0246(89), Washington DC, June 1991.

Sezgen, O., Franconi, E.M., Koomey, J.G., Greenburg, S.E., Afzal, A., Shown, L., *Technology Data Characterizing Space Conditioning in commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0*, Ernest Orlando Lawrence Berkeley National Laboratory, LBL-37065, Berkeley, CA, December, 1995.

MODEL INPUT: Short-term price elasticity of service demand

VARIABLE NAME: ShortRunPriceElasofDmd

MODEL COMPONENT: Service Demand

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

CLASSIFICATION: Input from file KSDELA

DISCUSSION:

Table A-3 summarizes a literature review encompassing price response analyses of major fuel demands. Composite price elasticity of service demand estimates based upon these sources are included. Input values for the fuel and end-use specific elasticity parameters included in the module are OIAF estimates developed from within the range of empirical values in Table A-3.

Table A-3. Range of Demand Elasticity from the Literature

Author	Sector	Time Period	Fuel	Price Elasticities		Income Elasticities	
				Short-run	Long-run	Short-run	Long-run
Balestra & Nerlove (1966)	Residential-Commercial	1957-62	Gas		-0.63		0.62
Joskow & Baughman (1976)	Residential-Commercial	1968-72	Gas	-0.15	-1.01	0.08	0.52
Fuss, Hydman & Waverman (1977)	Commercial	1960-71	Gas		-0.72		
Berndt & Watkins (1977)	Residential-Commercial	1959-74	Gas	-0.15	-0.68	0.04	0.133
Griffin (1979)	Commercial	1960-72	Gas	-0.83	-1.60		
Beierlin, Dunn & McConnor (1981)	Commercial	1967-77	Gas	-0.161	-1.06	-0.33	-2.19
Beierlin, Dunn & McConnor (1981)	Commercial	1967-77	Gas	-0.276	-1.865	0.035	0.237
Beierlin, Dunn & McConnor (1981)	Commercial	1967-77	Gas	-0.366	-2.258	0.034	0.210
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	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		Gas Distillate	-0.38 -0.55	large -0.55	0.73 0.73	large 0.73

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.

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 Commercial Module, since projections from the NEMS Renewable Fuels Module are not currently available at the level of disaggregation required by the Commercial Module. 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 heat pumps in the technology characterization menu, allowing geothermal technologies to compete in the marketplace. Consumption of the renewable fuels of wood and municipal solid waste (MSW) in the cogeneration of electricity is also modeled explicitly, using data from the EI-860: Annual Electric Generator Report data base.

SOURCES:

Energy Information Administration, EI-860: Annual Electric Generator Report data base.

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.

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 KTECH

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 Commercial Module. 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 No. 117934, prepared for U.S. Department of Energy, Energy Information Administration, September 2004.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, Reference No. 40222, prepared for U.S. Department of Energy, Energy Information Administration, January 2006.

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: Base year equipment market share

VARIABLE NAME: TechShareofServiceBASE

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 KTECH

DISCUSSION:

Base year market shares for the representative technologies included in the technology characterization data base are computed based primarily upon consumption patterns from the 2003 CBECS. The computed shares represent the proportion of *demand* that is satisfied by the particular technology characterized by building type for ventilation 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. These shares are computed 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:

Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Public Use Files, Washington DC, web site http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

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 Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, Reference No. 40222, prepared for U.S. Department of Energy, Energy Information Administration, January 2006.

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. The principal data sources for these inputs are cited below. These sources include Koomey (LBNL), DAC/SAIC, 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 requirement 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, since these limited data preclude the development of risk-adjusted time preferences as functions of technology characteristics, an average distribution across all technologies is applied.

The average consumer risk-adjusted time preference distribution is calculated as follows. Each source lists the proportions of commercial sector consumers with payback requirements by year, from zero to ten years. These payback requirements are first converted to implied internal rates of return for each year of the distribution for each source.[32] Then the risk-free interest rate (for purposes of the study, the 10 year Treasury bond rate for the year corresponding to the payback study was used) is subtracted from each implied rate of return to yield a consumer risk-adjusted time preference premium distribution for each source.[33] Each distribution is discrete, consisting of eleven cells, corresponding to the eleven payback years. These are subjected to a simple arithmetic average across studies to form a composite distribution.[34] Finally, the resulting average distribution is aggregated to yield a distribution of six risk-adjusted time preference

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

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

[34]The proportions for the eleven 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.

segments. A seventh risk-adjusted time preference segment has been added to represent the risk-free interest rate, the rate at which the Federal government is mandated to make purchase decisions. To model energy efficiency programs targeted at commercial lighting, the results of the average distribution have been modified for this end use. Further discussion of this and lists of the distributions from each source as well as the resulting values assumed for input into NEMS may be found 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 assumed constant over the projection period. However, the Commercial Sector Demand Module allows variation in the distribution on an annual basis to accommodate simulation of policy scenarios targeting consumers' implicit discount rates.

SOURCES:

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.

Decision Analysis Corporation of Virginia and 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 3, 1992, p. 14.

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 KTECH

DISCUSSION:

Capital and installation costs are combined to form installed capital costs, based upon available data. The Technology Choice algorithm does not require the separation of capital and installation costs, and currently does not retain information describing absolute equipment capacity. Installed unit capital costs (installed capital cost per thousand Btu/hr output capacity, per 1000 lumens in the case of lighting, or per 1000 cfm 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 No. 117934, prepared for U.S. Department of Energy, Energy Information Administration, September 2004.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, Reference No. 40222, prepared for U.S. Department of Energy, Energy Information Administration, January 2006.

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: Equipment Availability

VARIABLE NAME: TechAvailability

MODEL COMPONENT: Technology Choice

DEFINITION: Availability of equipment technology/model by year

CLASSIFICATION: Input from file KTECH

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. 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:

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, Reference No. 117934, prepared for U.S. Department of Energy, Energy Information Administration, September 2004.

Navigant Consulting, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies*, Reference No. 40222, prepared for U.S. Department of Energy, Energy Information Administration, January 2006.

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: degred, eleff, eqlife, taxlife, decliningbalancepercent, instcost, capcost, maintcst, avail, whrecovery, txcrpct, txcrmax, kW, lossfac, netmeteradj, operhours, solarins, ifirstyr, ilastyr, ifueltype, equipname, intervalcst, iintervalYrs

MODEL COMPONENT: CDistGen

DEFINITION:

Cost and performance of specific technologies (system capacity, cost per kW, 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 (this allows tax credit policies to be included in the economic considerations). In particular there is a permanent commercial tax credit for photovoltaics of up to 10% of the installed cost with a maximum in any one year of $25,000 (any credit above $25,000 may be carried over to the next tax year). The Energy Policy Act of 2005 (EPACT05) increases the commercial tax credit for photovoltaics to 30% of the installed cost for systems installed in 2006 and 2007. EPACT05 also provides commercial tax credits for fuel cells of up to 30% of the installed cost with a maximum of $500 per 0.5 kilowatt of capacity and for microturbines of up to 10% of the installed cost with a maximum of $200 per kilowatt of capacity. The EPACT05 fuel cell and microturbine tax credits are applicable to systems installed in 2006 and 2007.

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. This window is flexible in the number of years it represents, and new technologies don't necessarily have to be different from the previous version. Currently, annual characterizations for each technology are provided from the first year of model operation (2000) through the end of the projection period (2030).

Economic assumptions (tax rate, tax lives, decliningbalancepercent for depreciation allowances)

CLASSIFICIATION: Input from file KGENTK

DISCUSSION:

degred (technology, vintage) – degradation of conversion efficiency of technology. Currently applies to photovoltaics (PV) at a loss of 1 percent of total output per year. That is after 20 years, a 5 kW system would produce only 80 percent (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.

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

decliningbalancepercent (technology, vintage) - percentage to be used for depreciation calculation. A value of 100 percent 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, PV is automatically set to 200 percent per current tax law.

whrecovery (technology, vintage) – waste heat recovery factor for technologies that burn fuel (i.e., 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 2003 dollars per kW.

capcost (technology, vintage) – capital cost of the investment in 2003 dollars per kW.

maintcost (technology, vintage) – annual maintenance cost in 2003 dollars per kW.

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

txcreditpct (technology, vintage) – tax credit percentage that applies to a given technology's total installed cost (if any).

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

kW (technology, vintage) – kW of typical system. Note capacity must remain constant across vintages for a given 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.

netmeteradj (Census division, technology) – for solar technologies a percentage scalar that applies to the retail rate of electricity for sales to the grid (i.e., reverse flows of energy into the grid), currently set to 1.0 to compensate sales at the retail price. Any data for other technologies should be ignored since a grid sales price is now provided by the NEMS Electric Market Module.

solarins (Census division) – solar insolation for photovoltaics (in kWh per square foot per year) provided by NREL.

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 is 2 for natural gas which is used by fuel cells.

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

intervalcst (technology = 1, vintage) – interval maintenance cost for photovoltaic system inverter replacement.

iintervalYrs (technology = 1, vintage) – inverter replacement interval in years for photovoltaic systems.

SOURCES:

System Capacities and Operating Hours are Energy Information Administration assumptions.

Solar Insolation - NREL communication to US DOE EE.

Solar Photovoltaic Technology Specifications - Solar Energy Industries Association, *Our Solar Power Future – The U.S. Photovoltaic Industry Roadmap through 2030 and Beyond*, September 2004.

Fossil-Fired Technology Specifications - Discovery Insights, LLC, *FINAL REPORT Commercial and Industrial CHP Technology Cost and Performance Data Analysis for EIA's NEMS*, prepared for U.S. Department of Energy – Energy Information Administration, February 2006.

PV 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 cashflow 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 cashflow model in order to make the flows correspond to the nominal dollar loan payments. The current assumption is 3% annually.

SOURCES:

Energy Information Administration. Estimated values and assumptions.

MODEL INPUT: Distributed Generation Program-Driven Penetrations

VARIABLE NAMES: exogpen, bldgshr

MODEL COMPONENT: CDistGen

DEFINITION: Exogenous, program-driven cumulative installed units by Census division and technology. These are viewed as non-economic 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: Database from DOE PV program, News releases – DOE and industry, UPVG website, and Million Solar Roofs website.

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

MODEL INPUT: Distributed Generation Building-Specific Energy Use Characteristics

VARIABLE NAMES: elecavgkwh, waterhtgmmbtu, spacehtgmmbtu

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:

elecavgkwh – average annual electricity usage in kWh (kwh per year)

waterhtgmmbtu – average annual water heating EUI MMBtu/year

spacehtgmmbtu –average space water heating EUI MMBtu/year

SOURCES:

Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Public Use Files, Washington DC, web site http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html.

MODEL INPUT: Distributed Generation Penetration Function Parameters

VARIABLE NAMES: alpha, penparm

MODEL COMPONENT: CDistGen

DEFINITION: Technology-specific penetration function parameters.

CLASSIFICIATION: Input from file KGENTK

DISCUSSION:

The values for the penetration function parameters are found in each technology's characterization data in file KGENTK.txt of the *AEO2007* archive package cited in Appendix D.

SOURCES:

Energy Information Administration. Assumptions.

Appendix B. Mathematical Description

Introduction

This section provides the formulae and associated mathematical description which represent the detailed solution algorithms arranged by sequential submodule as executed in the NEMS Commercial Sector Demand Module. The exception to this order is that items pertaining to the Distributed Generation and Combined Heat and Power Submodule are found at the end of Appendix B. 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 Tables 1 and 2 of Chapter 2:

Subscript	Description of Dimension Represented by Subscript
r	Census division
b	NEMS Commercial Module 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 upon usage
t'	alternate technology class, for comparison with technology class t
v'	alternate vintage of floorspace or model of equipment, depending on usage
p	consumer risk-adjusted time preference premium segment
y	year designation (unless otherwise indicated, year ranges from 2004 through 2030, with the year 2004 indexed to the value of 15 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

Subscript	Description of Dimension Represented by Subscript
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
$\ni$	such that
$\exists$	there exists
$\nexists$	there doesn't exist
$\cdot$	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 formulae are evaluated only for the current year of the projections. 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 equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name. The equations 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:

$$CMSurvRate\left(b, y - y_0\right) \equiv \frac{1}{1 + \left(\dfrac{y - y_0}{CMAvgAge\left(b\right)}\right)^{CMGamma\left(b\right)}} \quad \textbf{(B - 1)}$$

$$y_0 \equiv year\ of\ construction$$

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

$$CMNewFloorSpace_{r,b,y'} = \frac{CBECSFlrSpc_{r,b,v}}{CMSurvRate(b, CBECSyear - y')} \quad \textbf{(B - 2)}$$

$$y' \equiv original\ year\ of\ construction = CMVintage_{r,b,v}$$

where v ranges over each of the nine floorspace vintage ranges and represents the median year of construction within the intervals of: 1) prior to 1900; 2) 1900-1919; 3) 1920-1945; 4) 1946-1959; 5) 1960-1969; 6) 1970-1979; 7) 1980-1989; 8) 1990-1999; and 9) 2000-2003. In this case, y' ranges from 1825 through 2003.

Previously-constructed floorspace surviving into the current year:

$$SurvFloorTotal_{r,b,y} = \sum_{y' = CMOldestBldgVint}^{y-1} \left[CMNewFloorSpace_{r,b,y'} \cdot CMSurvRate\left(b, y - y'\right)\right] \quad \textbf{(B - 3)}$$

First iteration estimate of new floorspace construction:

$$\widetilde{CMNewFloorSpace}_{r,b,y} = CMTotalFlspc_{r,b,CBECSyear} \cdot \frac{\sum_{b'}\left[DRItoCBECS_{b,b'} \cdot MC\_COMMFLSP_{r,b',y}\right]}{\sum_{b'}\left[DRItoCBECS_{b,b'} \cdot MC\_COMMFLSP_{r,b',CBECSyear}\right]} - SurvFloorTotal_{r,b,y} \quad \textbf{(B - 4)}$$

Note the use of the tilde (~) indicates the first estimate of a variable that is iteratively calculated twice in the system of equations B-4 through B-10.

First iteration estimate of total commercial floorspace:

$$\widetilde{CMNewFloorSpace}_{r,b,y} = \text{MAX}\left(\widetilde{CMNewFloorSpace}_{r,b,y}, 0\right) \qquad \textbf{(B - 5)}$$

$$\widetilde{CMTotalFlspc}_{r,b,y} = SurvFloorTotal_{r,b,y} + \widetilde{CMNewFloorSpace}_{r,b,y} \qquad \textbf{(B - 6)}$$

Ratio between Macro Model and first estimate Commercial Module floorspace growth rates:

$$CDRatio_r = \left(\frac{MC\_COMMFLSP_{r,1,y}}{MC\_COMMFLSP_{r,1,CBECSyear}}\right) \div \left(\frac{\sum_b \widetilde{CMTotalFlspc}_{r,b,y}}{\sum_b CMTotalFlspc_{r,b,CBECSyear}}\right) \qquad \textbf{(B - 7)}$$

Where the value of 1 for the middle subscript of *MC_COMMFLSP* denotes the Census division total commercial floorspace, across all NEMS MAM building types.

$$CMNewFloorSpace_{r,b,y} = CMTotalFlspc_{r,b,CBECSyear} \cdot \frac{\sum_{b'}\left[DRItoCBECS_{b,b'} \cdot MC\_COMMFLSP_{r,b',y}\right]}{\sum_{b'}\left[DRItoCBECS_{b,b'} \cdot MC\_COMMFLSP_{r,b',CBECSyear}\right]} \cdot CDRatio_r - SurvFloorTotal_{r,b,y} \qquad \textbf{(B - 8)}$$

Revised projection of new commercial floorspace construction and total floorspace:

$$CMNewFloorSpace_{r,b,y} = \text{MAX}\left(CMNewFloorSpace_{r,b,y}, 0\right) \qquad \textbf{(B - 9)}$$

$$CMTotalFlspc_{r,b,y} = SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y} \qquad \textbf{(B - 10)}$$

Service Demand Equations

Total Energy Use Intensities:

$$ComEUI_{r,b,s,F} = \sum_{f \in \{\ Major\ Fuels\ \}} ComEUI_{r,b,s,f} \qquad \textbf{(B - 11)}$$

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:

$$\begin{aligned}
&If\ \ BaseYrPCShrofOffEqEUI \geq 0\ \ Then \\
&\quad ComEUI_{r,b,s=NonPCOffEq,\,f} = ComEUI_{r,b,s=PCOffEq,\ f} \cdot (1 - BaseYrPCShrofOffEqEUI) \\
&\quad ComEUI_{r,b,s=PCOffEq,\ f} = ComEUI_{r,b,s=PCOffEq,\ f} \cdot BaseYrPCShrofOffEqEUI \\
&\qquad for \quad f \in \{\ MajorFuels\ \} \\
&Otherwise,\ \ unchanged
\end{aligned} \qquad \textbf{(B - 12)}$$

Total consumption by end-use in CBECSyear:

$$CforStotal_{[\ r,s\ ]} = \sum_{b} [\ ComEUI_{r,b,s,F} \cdot CMTotalFlspc_{r,b,CBECSyear}\ ] \qquad \textbf{(B - 13)}$$

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

$$\begin{aligned}
&CforSrestrict_{[\ t,v,r,s\ ]} = \\
&\quad \sum_{b} [\ ComEUI_{r,b,s,F} \cdot CMTotalFlspc_{r,b,CBECSyear} \cdot (\ 1 - EquipRestriction_{t,v,b,r}\ )\ ] \\
&if \quad Techavailability_{t,v,1} \leq CBECSyear
\end{aligned} \qquad \textbf{(B - 14)}$$

Revise initial equipment market shares to reflect building restrictions:

$$TechShareofServiceBASE_{r,b,s,t,v} = TechShareofServiceBASE_{r,b,s,t,v} \cdot \frac{CforStotal}{CforSrestrict},$$
$$\text{if} \quad EquipRestriction_{t,v,b,r} = 0$$
$$\text{and} \quad TechAvailability_{t,v,1} \leq CBECSyear \qquad \textbf{(B - 15)}$$

$$TechShareofService_{r,b,s,t,v} = \frac{TechShareofServiceBASE_{r,b,s,t,v}}{\sum_{b'} \sum_{t',v'} TechShareofServiceBASE_{r,b',s,t',v'}}$$
$$\text{if} \quad TechAvailability_{t',v',1} \leq CBECSyear \qquad \textbf{(B - 16)}$$
$$\text{and} \quad TechAvailability_{t,v,1} \leq CBECSyear$$

Here, b' is used as an alternative NEMS Commercial Module building type index rather than as a NEMS MAM building type index, in order 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:

$$AverageEfficiencyBASE_{r,b,s,f} = \frac{\sum_{\forall t,v \ni FuelbyTech(t,f)=1} TechShareofServiceBASE_{r,b,s,t,v}}{\sum_{\forall t,v \ni FuelbyTech(t,f)=1} \left(\frac{TechShareofServiceBASE_{r,b,s,t,v}}{TechEff_{r,f,t,v}} \right)} \qquad \textbf{(B - 17)}$$

Apply fuel-specific factor to bring CBECSyear equipment market shares and EUI's into agreement:

$$KScale_f = \frac{\frac{ComEUI_{r,b,s,f}}{ComEUI_{r,b,s,F}} \cdot \left[\frac{AverageEfficiencyBASE_{r,b,s,f}}{\sum_{\forall t,v \ni FuelbyTech(t,f)=1} TechShareofServiceBASE_{r,b,s,t,v}} \right]}{\sum_{f' \in \{MajFl\}} \left[\frac{ComEUI_{r,b,s,f'}}{ComEUI_{r,b,s,F}} \cdot AverageEfficiencyBASE_{r,b,s,f'} \right]} \qquad \textbf{(B - 18)}$$

$$TechShareofServiceBASE_{r,b,s,t,v} = TechShareofServiceBASE_{r,b,s,t,v} \cdot KScale_f$$
$$\textbf{(B - 19)}$$
$$f \in \{ Major\ Fuels \}; \forall t,v \ni FuelbyTech_{t,f} = 1$$

Service Demand Intensities (SDI) prevailing in the CBECS Base Year:

$$ServDmdIntenBASE_{s,b,r} = \frac{ComEUI_{r,b,s,F}}{\sum\limits_{\forall t,v \ni TechEff_{r,s,t,v} \neq 0} \left(\frac{TechShareofServiceBASE_{r,b,s,t,v}}{TechEff_{r,s,t,v}} \right)} \qquad \textbf{(B - 20)}$$

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

$$ServDmdIntenBASE_{s,b,r} = ComEUI_{r,b,s,F} \qquad \textbf{(B - 21)}$$

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

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

$$ServDmdExBldg_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \cdot 10^{-3} \cdot SurvFloorTotal_{r,b,y} \qquad \textbf{(B - 22)}$$

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

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

Calculate the current year efficiency of surviving base-year floorspace (upper bound is new shell efficiency):

$$ExistShBaseStock_{s,b,r,y} = \left(Maximum(ExistImprov, ShellEffIndex_{b,r,2})^{\frac{1}{(2030-CBECSyear)}} \right)^{(y-CBECSyear)} \qquad \textbf{(B - 23)}$$

$$s \in \{ SpHeat, SpCool \}$$

Compute the heating efficiency index of surviving floorspace as weighted average of surviving base-year stock and post base-year additions:

$$ShellEffIndex_{b,r,1} = ExistShBaseStock_{s,b,r,y} \cdot \left(SurvFloorTotal_{r,b,y} - TotNewFS\right) + \sum_{y'=CMFirstYr}^{y-1} \left[CMNewFloorspace_{r,b,y'} \cdot ShellEffIndex_{b,r,2} \cdot \left(NewImprv^{\frac{1}{(2030-CBECSyear)}} \right)^{(y'-CBECSyear)} \right]$$

$$s \in \{ SpHeat, SpCool \} \qquad \textbf{(B - 24)}$$

Interpolate effect of improving shell efficiencies on service demands in surviving floorspace:

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot ShellEffIndex_{b,r,1}$$

$$s \in \{ SpHeat \} \qquad \textbf{(B - 25)}$$

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot \left[\left(ShellEffIndex_{b,r,1} - 1.0\right) \cdot (-0.1) + 1.002 \right]$$

$$s \in \{ SpCool \} \qquad \textbf{(B - 26)}$$

Equation B-26 expresses the assumed trade-off between protecting an existing commercial building against heat loss and the need to provide additional cooling (during the cooling season) to remove heat from lighting and other internal sources of "waste" heat.

Basic projection of service demands in new floorspace construction:

$$NewServDmd_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \cdot 10^{-3} \cdot CMNewFloorspace_{r,b,y}$$

$$s \in \{ Major\ Services \} \qquad \textbf{(B - 27)}$$

The 10^{-3} in Equation B-27 converts units from billion Btu to trillion Btu.

Calculate the current year improvement to new heating shell efficiency:

$$NewShAdj = \left(NewImprv^{\frac{1}{(2025\text{-}CBECSyear)}} \right)^{(y\text{-}CBECSyear)} \qquad \textbf{(B - 28)}$$

$$s \in \{ SpHeat, SpCool \}$$

Interpolate effect of improving shell efficiencies on service demands in new floorspace:

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot ShellEffIndex_{b,r,2} \cdot NewShAdj \qquad \textbf{(B - 29)}$$

$$s \in \{ SpHeat \}$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot \left[\left(ShellEffIndex_{b,r,2} \cdot NewShAdj - 1.0 \right) \cdot (-0.0309) + 1.0315 \right] \qquad \textbf{(B - 30)}$$

$$s \in \{ SpCool \}$$

Equation B-30 expresses the trade-off between protecting a commercial building against heat loss and the need to provide additional cooling (during the cooling season) to remove heat from lighting and other internal sources of "waste" heat for new floorspace. It is based on data provided in a study of space conditioning and thermal integrity in support of the Department of Energy's Office of Energy Efficiency and Renewable Energy.[35]

Calculation of data center share of large office floorspace:

$$\begin{aligned} DatCtrShare = {} & 0.000002 \cdot (y - CMFirstYr)^3 \\ & - 0.00002 \cdot (y - CMFirstYr)^2 + 0.0006 \cdot (y - CMFirstYr) \\ & + .00095 \\ & \text{where } CMFirstYr = CBECSyear + 1 \\ & \text{if } y > ksteoyr \\ & \text{otherwise}, 0 \end{aligned} \qquad \textbf{(B - 31)}$$

[35] Sezgen, O., Franconi, E.M., Koomey, J.G., Greenburg, S.E., Afzal, A., Shown, L., Technology Data Characterizing Space Conditioning in commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0, Ernest Orlando Lawrence Berkeley National Laboratory, LBL-37065, Berkeley, CA, December, 1995.

Equation B-31 expresses the assumed share of large office floorspace attributed to data centers to account for the additional services required by these facilities.[36]

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

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot (1 - DatCtrShare) + ServDmdExBldg_{s,b,r,y} \cdot DatCtrShare \cdot dcf_s \quad \textbf{(B - 32)}$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot (1 - DatCtrShare) + NewServDmd_{s,b,r,y} \cdot DatCtrShare \cdot dcf_s \quad \textbf{(B - 33)}$$

$$s \in \{ SpCool, Ventilation, Other \}$$
$$b \in \{ Large\, Office \}$$

Where dcf_s is the ratio of the service demand intensity in data centers to the service demand intensity of large office buildings for service s.

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

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot \frac{ServicedFlspcProp_{b,s,new}}{ServicedFlspcProp_{b,s,existing}} \quad \textbf{(B - 34)}$$
$$s \leq CMnumVarSDI$$

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

$$ServDmdExBldg_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \cdot 10^{-3} \cdot SurvFloorTotal_{r,b,y} \quad \textbf{(B - 35)}$$
$$s \in \{ MinorServices \}$$

$$NewServDmd_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \cdot 10^{-3} \cdot CMNewFloorspace_{r,b,y} \quad \textbf{(B - 36)}$$
$$s \in \{ Minor\ Services \}$$

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

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[36] Data center floorspace estimates are based on Mitchell-Jackson, Jennifer, :Energy Needs in an Internet Economy: A Closer Look at Data Centers," Laurence 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.

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

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot MarketPenetration_{s,y} \cdot NonspecMiscShr_b \qquad \textbf{(B - 37)}$$

$$s \in \{OfficeEquipment : PC,\ OfficeEquipment : NonPC,\ Other : Non-specific\}$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot MarketPenetration_{s,y} \cdot NonspecMiscShr_b \qquad \textbf{(B - 38)}$$

$$s \in \{OfficeEquipment : PC,\ OfficeEquipment : NonPC,\ Other : Non-specific\}$$

The variable $NonspecMiscShr_b$ is involved in the calculations only for non-specific uses within the "Other" end-use service category.

Service demand projections for specified categories within the "Other" end-use service category, including continuing market penetration, are based on electricity consumption estimates and projected national-level trends from a September 2006 study completed by TIAX LLC.[37] Polynomial equations are fitted to the trends to describe the projected end-use energy 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.[38]

Total U.S. floorspace of building types with demand for the type of services in a specific category of electricity-based services within "Other":

$$TotMiscFloorspace_{mc,[y]} \equiv \sum_{r} \sum_{b \in mc} \left(SurvFloorTotal_{r,b,y} + CMNewFloorspace_{r,b,y} \right) \qquad \textbf{(B - 39)}$$

$$mc \in \{Specific\ miscellaneous\ use\ categories\ within\ Other\}$$

$TotMiscFloorspace_{mc,[y]}$ is the total U.S. floorspace of building types with demand for the type of services in category *mc* ($b \in mc$). For example, service demand for MRIs and CT Scanners would be limited to healthcare floorspace, while distribution transformers are found in all types of commercial buildings.

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

[38] The exception to this treatment is municipal water services. Electricity consumption for water services is included in non-building energy consumption with specific equations described in the Benchmarking Equations section.

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

$$USMiscElDmd_{mc,[y]} = \left(MiscK3_{mc} \cdot \Delta y^3 + MiscK2_{mc} \cdot \Delta y^2 + MiscK1_{mc} \cdot \Delta y + MiscK0_{mc}\right) \cdot 10^{-3} \cdot TotMiscFloorspace_{mc,[y]} \qquad \textbf{(B - 40)}$$

$$mc \in \{Specific\ miscellaneous\ use\ categories\ within\ Other\}$$

Where $\Delta y \equiv y - CBECSyear$, the number of years between the current year and the commercial base year. The 10^{-3} in this equations converts units from billion Btu to trillion Btu. Coefficient values associated with each miscellaneous use category are provided in Appendix A.

Service demand for specific categories of electricity-based "Other" services by Census division and building type:

$$MiscElDmd_{mc,r,b,y} = USMiscElDmd_{mc,[y]} \cdot \frac{TotalFloorspace_{r,b,y}}{TotMiscFloorspace_{mc,[y]}}, \quad b \in mc$$

$$MiscElDmd_{mc,r,b,y} \equiv 0, \quad otherwise \qquad \textbf{(B - 41)}$$

$$TotExplicitMiscElDmd_{r,b,y} = \sum_{mc} MiscElDmd_{mc,r,b,y}$$

$$mc \in \{Specific\ miscellaneous\ use\ categories\ within\ Other\} \qquad \textbf{(B - 42)}$$

Where $TotalFloorspace_{r,b,y}$ is the sum of $SurvfloorTotal_{r,b,y}$ and $CMNewFloorspace_{r,b,y}$.

Add service demand for specific categories to demand for "Other" services:

$$ServDmdExBldg_{10,b,r,y} = ServDmdExBldg_{10,b,r,y} + \left(TotExplicitMiscElDmd_{r,b,y} \cdot \frac{SurvFloorTotal_{r,b,y}}{TotalFloorspace_{r,b,y}}\right) \qquad \textbf{(B - 43)}$$

$$NewServDmd_{10,b,r,y} = NewServDmd_{10,b,r,y} + \left(TotExplicitMiscElDmd_{r,b,y} \cdot \frac{CMNewFloorspace_{r,b,y}}{TotalFloorspace_{r,b,y}}\right) \qquad \textbf{(B - 44)}$$

Where $TotalFloorspace_{r,b,y}$ is the sum of $SurvfloorTotal_{r,b,y}$ and $CMNewFloorspace_{r,b,y}$.

Reduce demands by amounts satisfied using solar energy directly:

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - \left(\frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} \cdot \frac{SurvFloorTotal_{r,b,y}}{TotalFloorspace_{r,b,y}} \right) \quad \textbf{(B - 45)}$$

$$s \in \{ \ Solar\ Services \ \}$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} - \left(\frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} \cdot \frac{CMNewFloorspace_{r,b,y}}{TotalFloorspace_{r,b,y}} \right) \quad \textbf{(B - 46)}$$

$$s \in \{ \ Solar\ Services \ \}$$

Where $TotalFloorspace_{r,b,y}$ is the sum of $SurvfloorTotal_{r,b,y}$ and $CMNewFloorspace_{r,b,y}$.

Amount of service demand requiring replacement equipment due to equipment failure:

$$RetireServDmd_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot \sum \left(\frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}} \right) \quad \textbf{(B - 47)}$$

$$\forall \ t \ni TechbyService_{s,t} = 1$$

Amount of service demand satisfied by working equipment, but subject to the retrofit decision:

$$ServDmdSurv_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - RetireServDmd_{s,b,r,y} \quad \textbf{(B - 48)}$$

$$y > CMFirstYr$$

Technology Choice Equations

Proportion of service demand affected by failed equipment:

$$ReplacementProportion_{r,b,s} = \sum\left(\frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}}\right) \qquad \textbf{(B - 49)}$$

$$\forall\, t,v \ni TechbyService_{s,t} = 1$$

Equipment share of service demand not requiring equipment replacement:

$$SurvivingShareofService_{r,b,s,t,v} = PrevYrTechShareofService_{r,b,s,t,v} \cdot \frac{\left(1 - \dfrac{1}{TechLife_{t,v}}\right)}{1 - ReplacementProportion_{r,b,s}} \qquad \textbf{(B - 50)}$$

$$\forall\, t,v \ni TechbyService_{s,t} = 1$$

Fuel shares of service demand not requiring equipment replacement:

$$SurvivingFuelShareofService_{r,b,s,f} = \sum\left\lfloor SurvivingShareofService_{r,b,s,t,v} \cdot FuelbyTech_{t,f} \right\rfloor \qquad \textbf{(B - 51)}$$

$$\forall\, t,v \ni TechbyService(s,t) = 1$$

Failed equipment shares of service demand requiring equipment replacement:

$$ReplacementShareofService_{r,b,s,t,v} = \frac{PrevYrTechShareofService_{r,b,s,t,v} \cdot \left[\dfrac{1}{TechLife_{t,v}}\right]}{ReplacementProportion_{r,b,s}} \qquad \textbf{(B - 52)}$$

Fuel shares of service demand requiring equipment replacement:

$$ReplacementFuelShareofService_{r,b,s,f} = \sum(ReplacementShareofService_{r,b,s,t,v} \ FuelbyTech_{t,f}) \quad \text{(B - 53)}$$
$$\forall\, t,v \ni TechbyService_{s,t} = 1$$

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

$$TechCost_{t,v,1} = TechCost_{t,v,1} - TechCost_{CoolingTechIndexHP,v,1} \quad \text{(B - 54)}$$
$$t,v \in \{Heatpumps\ for\ SpHeat\}$$

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

Cost Trend Function when flag CostTrendSwitch is set to one:

$$KEqCost\ (t,v,y,"CAP") \equiv$$
$$for\ Infant\ technologies:$$
$$\frac{TechCost_{t,v,1} \cdot \delta}{1+\left(\frac{y-y_1}{y_0-y_1}\right)^{\gamma}} + (1-\delta) \cdot TechCost_{t,v,1}$$
$$for\ Adolescent\ technologies:$$
$$\frac{TechCost_{t,v,1} \cdot 2\delta}{1+\left(\frac{y-y_1}{y_0-y_1}\right)^{\gamma}} + (1-\delta) \cdot TechCost_{t,v,1}$$
$$for\ Mature\ technologies \quad \text{(B - 55)}$$
$$TechCost_{t,v,1}$$
$$\gamma \equiv shape\ parameter\ corresponding\ to\ the\ rate\ of\ price\ decline,$$
$$\delta \equiv total\ anticipated\ percentage\ decline\ in\ real\ cost\ from\ the\ initial\ value,$$
$$y_0 \equiv year\ dictating\ the\ curve's\ inflection\ point,$$
$$y_1 \equiv effective\ year\ of\ introduction\ for\ the\ given\ technology$$

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

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

$$ShellEffFactor_{x} = ShellEffIndex_{b,r,x}$$

$$s \in \{ SpHeat \} \qquad \textbf{(B - 56)}$$

Modify the space heating indices by the adjustment for thermal integrity to obtain the space cooling shell efficiency factor:

$$ShellEffFactor_{1} = (ShellEffIndex_{b,r,1} - 1) \cdot -0.1 + 1.002$$

$$ShellEffFactor_{2} = (ShellEffIndex_{b,r,2} \cdot NewShAdj - 1) \cdot -0.0309 + 1.0315 \qquad \textbf{(B - 57)}$$

$$s \in \{ SpCool \}$$

Equation B-57 expresses the assumed trade-off between protecting a commercial building against heat loss and the need to provide additional cooling (during the cooling season) to remove heat from lighting and other internal sources of “waste” heat. The relationship for existing buildings, $ShellEffFactor_1$, is by assumption; the relationship for new construction is based on data provided in a study of space conditioning and thermal integrity in support of the Department of Energy’s Office of Energy Efficiency and Renewable Energy.[39]

Effective hurdle (implicit discount) rate:

$$Hurdle = \frac{MC\_RMGBLUSREAL_{y}}{100} + TimePrefPrem_{s,p,y} \qquad \textbf{(B - 58)}$$

$$EffectHurdle \equiv$$

$$Hurdle, \quad for\ Hurdle \leq 0.15 \quad or \quad Pr_{f,r,y,s} \leq Pr_{f,r,CBECSyear,s} \qquad \textbf{(B - 59)}$$

$$0.15 + (Hurdle - 0.15) \cdot \left(\frac{Pr_{f,r,y,s}}{Pr_{f,r,CBECSyear,s}} \right)^{HurdleElas_{r,s,f}}, \quad otherwise$$

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[39] Sezgen, O., Franconi, E.M., Koomey, J.G., Greenburg, S.E., Afzal, A., Shown, L., Technology Data Characterizing Space Conditioning in commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0, Ernest Orlando Lawrence Berkeley National Laboratory, LBL-37065, Berkeley, CA, December, 1995.

Where $P_{rf,r,y,s}$ 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). The subscript *y* is expressed as a calendar year in the third term.

Annualized cost of new equipment:

$$AnnualCostTech_{p,t,v} = KEqCost(t,v,y,"CAP") \cdot \frac{EffectHurdle}{1-(1+EffectHurdle)^{-TechLife_{t,v}}}$$

$$+ TechCost_{t,v,2} \cdot CapacityFactor_{r,b,s}$$

$$+ ShellEffFactor_{x} \cdot \frac{ConvFactor}{TechEff_{r,s,t,v}} \cdot CapacityFactor_{r,b,s} \cdot FuelCost_{f_t,r,y,s} \qquad \textbf{(B - 60)}$$

$$ConvFactor \equiv 8.76 \text{ for } s \neq lighting;\ 0.03343^{-1} / TechCRI(r,s,t,v) \text{ for } s = lighting$$

$$f_t \equiv \text{fuel used by } t$$

Where 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* is the effective hurdle or implicit discount rate for the current fuel, Census division, service and year, as calculated in equations B-58 and B-59. The variable *ShellEffFactor* is involved in the calculation only for space heating and space cooling. Because only the relative costs of choices are important within a given 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 a given building type and Census division. $FuelCost_{f_t,r,y,s}$ 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-61 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 kW-year (necessary since lighting efficiency is in lumens per watt). Equation 54 also includes an adjustment for *TechCRI* the lighting “color rendering index” which reduces the “effective efficiency” of low CRI lighting technologies rendering them less attractive relative to higher CRI options.

Expression for FuelCost when optional price expectations are used:

$$FuelCost_{f_t,r,y,s} \equiv \frac{1}{TechLife_{t,v}} \cdot \sum_{y'=y}^{y+TechLife_{t,v}-1} Xprice_{f_t,r,y'} \qquad \textbf{(B - 61)}$$

$$f_t \equiv \text{fuel used by } t$$

Least Cost Decision Rule -- identify least cost equipment:

$$\text{Find } t, v \text{ such that } AnnualCostTech_{p,t,v} \leq AnnualCostTech_{p,t',v'} \ \forall\, t', v'$$
$$\text{then } LCTNRAF_{p,1} = t \text{ and } LCTNRAF_{p,2} = v \qquad \text{(B - 62)}$$

Where $LCTNRAF_{p,1}$ represents the technology class with the least annualized cost, and $LCTNRAF_{p,2}$ represents the technology model with the least annualized cost.

Same Fuel Decision Rule -- identify least cost equipment using the same fuel as the existing stock:

$$\text{Find } t, v \ni AnnualCostTech_{p,t,v} \leq AnnualCostTech_{p,t',v'} \ \forall t', v'$$
$$\ni FuelByTech(t', f) = FuelByTech(t, f) = 1,$$

$$\text{then } LCTNRSF_{p,f,1} = t \text{ and } LCTNRSF_{p,f,2} = v. \qquad \text{(B - 63)}$$

$$\text{If } \nexists\ t \ni FuelByTech(t, f) = 1, \text{then } LCTNRSF_{p,f,1} = LCTNRSF_{p,f,2} = 0$$
$$f \in \{\text{ Major Fuels }\}$$

Where $LCTNRSF_{p,f,1}$ represents the technology class with the least annualized cost, and $LCTNRSF_{p,f,2}$ represents the technology model with the least annualized cost.

Same Technology Decision Rule -- identify least cost model in current technology class:

$$\text{Find } v \text{ such that } AnnualCostTech_{p,t,v} \leq AnnualCostTech_{p,t,v'} \ \forall v'$$
$$\text{then } LCVNRST_{p,t} = v \qquad \text{(B - 64)}$$

Where $LCVNRST_{p,t}$ represents the technology model with the least annualized cost.

Market shares of equipment within least cost behavior segment of new and replacement decision types:

$$LCMSNR_{t,v} = \sum_{p} TimePrefProp_{s,p,y}$$
$$\forall\, p \ni LCTNRAF_{p,1} = t \text{ and } LCTNRAF_{p,2} = v \qquad \text{(B - 65)}$$

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

$$SFMSN_{t,v} = \sum [TimePrefProp_{s,p,y} \cdot PrevYrFuelShareofService_{r,b,s,f}] \quad \forall\, p \ni LCTNRSF_{p,f,1} = t, and\ LCTNRSF_{p,f,2} = v;\ f \in \{ MajFuels \} \tag{B - 66}$$

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

$$SFMSR_{t,v} = \sum [TimePrefProp_{s,p,y} \cdot ReplacementFuelShareofService_{r,b,s,f}] \quad \forall\, p \ni LCTNRSF_{p,f,1} = t, and\ LCTNRSF_{p,f,2} = v;\ f \in \{ MajFuels \} \tag{B - 67}$$

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

$$STMSN_{t,v} = \left[\sum_{\forall p \ni LCVNRST_{p,t} = v} TimePrefProp_{s,p,y} \right] \cdot \left[\sum_{\forall v'} PrevYrTechShareofService_{r,b,s,t,v'} \right] \tag{B - 68}$$

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

$$STMSR_{t,v} = \left[\sum_{\forall p \ni LCVNRST_{p,t} = v} TimePrefProp_{s,p,y} \right] \cdot \left[\sum_{\forall v'} ReplacementShareofService_{r,b,s,t,v'} \right] \tag{B - 69}$$

Equipment market shares within new decision type, consolidated across behavior segments:

$$\begin{aligned} MS_{b,s,1,t,v} = \ & BehaviorShare_{s,b,1,1} \cdot LCMSNR_{t,v} \\ & + BehaviorShare_{s,b,1,2} \cdot SFMSN_{t,v} \\ & + BehaviorShare_{s,b,1,3} \cdot STMSN_{t,v} \end{aligned} \tag{B - 70}$$

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:

$$\begin{aligned} MS_{b,s,2,t,v} = \ & BehaviorShare_{s,b,2,1} \cdot LCMSNR_{t,v} \\ & + BehaviorShare_{s,b,2,2} \cdot SFMSR_{t,v} \\ & + BehaviorShare_{s,b,2,3} \cdot STMSR_{t,v} \end{aligned} \tag{B - 71}$$

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:

$$ACE_{t,v,p} = TechCost_{t,v,2} \cdot CapacityFactor_{r,b,s}$$

$$- RetroCostFract_{t,v} \cdot KEqCost(t,v,y,"CAP") \cdot \frac{EffectHurdle}{1 - (1 + EffectHurdle)^{-TechLife_{t,v}}}$$

$$+ ShellEffFactor_{1} \cdot \frac{ConvFactor}{TechEff_{r,s,t,v}} \cdot \frac{CapacityFactor_{r,b,s}}{\frac{1}{2} TechLife_{t,v}} \cdot \sum_{y'=y}^{y+\frac{1}{2}\cdot TechLife_{t,v}-1} Xprice_{f_t,r,y'} \qquad \textbf{(B - 72)}$$

$$ConvFactor \equiv 8.76 \ \text{for } s \neq lighting;\ 0.03343^{-1} / TechCRI(r,s,t,v) \ \text{for } s = lighting$$

$$f_t \equiv \text{fuel used by } t$$

The variable *EffectHurdle* is the effective hurdle or implicit discount rate for the current fuel, Census division, service and year, as calculated in equations B-58 and B-59. The variable *ShellEffFactor* is involved in the calculation only for space heating and space cooling. Because only the relative costs of choices are important within a given building, the equation above is divided by *CapacityFactor*, which has the same value for all equipment providing a given service in a given 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 kW-year.

Identify least cost alternative for retrofit decision, following least cost behavior:

$$\begin{aligned} &\text{Find } t', v' \text{ such that } AnnualCostTech_{p,t',v'} \leq ACE_{t,v,p} \\ &\quad \text{if none found, set } t' = t, v' = v. \\ &\quad \text{If } t, v \text{ unavailable, set } t' = v' = 0 \\ &\text{then } LCTRetAF_{p,t,v,1} = t', LCTRetAF_{p,t,v,2} = v' \end{aligned} \qquad \textbf{(B - 73)}$$

Identify least cost retrofit alternative for same fuel behavior:

$$
\begin{aligned}
&Find\ t',v' \ni AnnualCostTech_{p,t',v'} \leq ACE_{t,v,p}\ ,\ f_{t'} = f_t \\
&If\ \nexists\ t',v', set\ t' = t\ , v' = v \\
&If\ \nexists\ t,v\ , set\ t' = v' = 0 \\
&then\ LCTRetSF_{p,t,v,1} = t'\ , LCTRetSF_{p,t,v,2} = v'
\end{aligned} \quad \textbf{(B - 74)}
$$

Identify least cost retrofit alternative for same technology behavior, when optional retrofitting is allowed:

$$
\begin{aligned}
&Find\ v' \ni AnnualCostTech_{p,t,v'} \leq ACE_{t,v,p}\ , \forall\ v' \\
&If\ \nexists\ v', set\ \ v' = v \\
&then\ LCVRetST_{p,t,v} = v'
\end{aligned} \quad \textbf{(B - 75)}
$$

Equipment market shares within least cost behavior segment of retrofit decision type:

$$
\begin{aligned}
&LCMSRet_{t,v} = \sum[TimePrefProp_{s,p,y} \cdot SurvivingShareofService_{t',v'}] \\
&\forall\ t',v' \ni LCTRetAF_{p,t',v',1} = t, LCTRetAF_{p,t',v',2} = v\ ; \forall\ p
\end{aligned} \quad \textbf{(B - 76)}
$$

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

$$
\begin{aligned}
&SFMSRet_{t,v} = \sum[TimePrefProp_{s,p,y} \cdot SurvivingShareofService_{t',v'}] \\
&\forall\ t',v' \ni LCTRetSF_{p,t',v',1} = t, LCTRetSF_{p,t',v',2} = v\ ; \forall\ p
\end{aligned} \quad \textbf{(B - 77)}
$$

$LCTRetSF_{p,t,v,1}$ 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.

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

$$
\begin{aligned}
STMSRet_{t,v} &= \sum[TimePrefProp_{s,p,y} \cdot SurvivingShareofService_{t,v'}] \\
&\forall\ v' \ni LCVRetST_{p,t,v'} = v\ ; \forall\ p, \quad if\ \ STRetBehav = 1 \\
&SurvivingShareofService_{t,v}\ , \qquad if\ \ STRetBehav = 0
\end{aligned} \quad \textbf{(B - 78)}
$$

$LCVRetST_{p,t,v'}$ represents the technology model with the least annualized cost for retrofit decisions

Equipment market shares within retrofit decision type, consolidated across behavior segments:

$$MS_{b,s,3,t,v} = BehaviorShare_{s,b,3,1} \cdot LCMSRet_{t,v} + BehaviorShare_{s,b,3,2} \cdot SFMSRet_{t,v} + BehaviorShare_{s,b,3,3} \cdot STMSRet_{t,v} \quad \textbf{(B - 79)}$$

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.

Heat pump market shares of space cooling service demand:

$$MS_{b,s=SPCool,d,t',v'} = \frac{MS_{b,s=SPHeat,d,t,v} \cdot SD_{s=SpHeat,d} \cdot \frac{DegreeDays_{s=SPCool,r,WthrYear}}{DegreeDays_{s=SPHeat,r,WthrYear}}}{SD_{s=SpCool,d}}, \quad if \ SD_{s=SpCool,d} > 0$$

$$MS_{b,s=SPCool,d,t',v'} = 0, \quad if \ SD_{s=SpCool,d} = 0$$

(B - 80)

$$for \ t,v \in \{Heatpumps \ for \ SpHeat\}$$
$$t',v' = same \ equipment \ as \ t,v \ except \ for \ SpCool$$
$$SD_{s,d} \equiv NSD_{r,b,s,y}, if \ d = 1$$
$$RSD_{r,b,s,y}, if \ d = 2$$
$$SSD_{r,b,s,y}, if \ d = 3$$
$$WthrYear = y \ (current \ year)$$

Amount of cooling service demand satisfied by heat pumps:

$$HeatPumpCoolingSD_d = SD_{s=SpCool,d} \cdot \sum_{t,v \in \{Heatpumps \ for \ SpCool\}} MS_{b,s=SpCool,d,t,v} \quad \textbf{(B - 81)}$$

$$Normalizer_d = \sum_{t,v \in \{SpCool \ equip \ other \ than \ heatpumps\}} MS_{b,s=SpCool,d,t,v} \quad \textbf{(B - 82)}$$

Adjusted market shares of space cooling equipment other than heat pumps:

$$MS_{b,s=SpCool,d,t,v} = \frac{MS_{b,s=SpCool,d,t,v}}{Normalizer_d} \cdot \frac{\left(SD_{s=SpCool,d} - HeatPumpCoolingSD_d\right)}{SD_{s=SpCool,d}}$$

(B - 83)

$$t,v \in \{\ SpCool\ equipment\ other\ than\ heatpumps\ \}$$

Fuel shares by fuel, decision type, service, building, and Census division:

$$FS_{r,b,s,d,f} = \sum_t \sum_v [\ MS_{b,s,d,t,v}\ \ FuelbyTech_{t,f}\ ]\ ,where\ FuelbyTech_{t,f} = 1\ if\ \ t\ uses\ \ f$$

$$0\ ,elsewhere$$

(B - 84)

$$f \in \{\ Major\ Fuels\ \}$$

Average equipment efficiency by fuel, decision type, service, building, and Census division:

$$AE_{r,b,s,d,f} = \frac{FS_{r,b,s,d,f}}{\sum_{t,v}\left[\frac{MS_{b,s,d,t,v} \cdot FuelbyTech_{t,f}}{TechEff_{r,s,t,v}}\right]}\ ,if\ \exists\, t\ ,v \ni MS_{b,s,d,t,v} \cdot FuelbyTech_{t,f} \neq 0$$

(B - 85)

$$0\ ,otherwise$$

$$f \in \{\ MajorFuels\ \}$$

Fuel shares by fuel, end-use, building, and Census division:

$$FuelShareofService_{r,b,s,f} = \frac{NSD_{r,b,s,y} \cdot FS_{r,b,s,1,f}}{TSD_{r,b,s,y}} + \frac{RSD_{r,b,s,y} \cdot FS_{r,b,s,2,f}}{TSD_{r,b,s,y}} + \frac{SSD_{r,s,b,y} \cdot FS_{r,b,s,3,f}}{TSD_{r,b,s,y}}$$

(B - 86)

$$where\ TSD_{r,b,s,y} > 0\ ,$$

$$0\ elsewhere$$

$$f \in \{\ MajFuel\ \}$$

$TSD_{r,b,s,y}$ is the total service demand, defined as $SSD_{r,b,s,y} + RSD_{r,b,s,y} + NSD_{r,b,s,y}$

Equipment market shares by equipment, end-use, building, and Census division:

$$TechShareofService_{r,b,s,t,v} = \frac{NSD_{r,b,s,y} \cdot MS_{r,b,s,1,t,v}}{TSD_{r,b,s,y}} + \frac{RSD_{r,b,s,y} \cdot MS_{r,b,s,2,t,v}}{TSD_{r,b,s,y}} + \frac{SSD_{r,s,b,y} \cdot MS_{r,b,s,3,t,v}}{TSD_{r,b,s,y}} \quad \textbf{(B - 87)}$$

$$where\ TSD_{r,b,s,y} > 0\ ,0\ elsewhere$$
$$\forall t\ ,v$$

Average equipment efficiency by fuel, end-use, building, and Census division:

$$AverageEfficiency_{r,b,s,f} = \frac{FuelShareofService_{r,b,s,f}}{\sum_{t,v}\left[\frac{TechShareofService_{r,b,s,t,v} \cdot FuelbyTech_{t,f}}{TechEff_{r,s,t,v}}\right]}$$

$$if\ \exists t \ni TechShareofService_{r,b,s,t,v} \cdot FuelbyTech_{t,f} \neq 0 \quad \textbf{(B - 88)}$$
$$0, otherwise$$
$$f \in \{\ MajorFuels\ \}$$

Average equipment efficiency for new decision type by fuel, end-use, and Census division:

$$DecAvgEff_{r,s,1,f,y} = \frac{\sum_b [\ FS_{r,b,s,1,f} \cdot NSD_{r,b,s,y}\ ]}{\sum_b\left[\frac{FS_{r,b,s,1,f} \cdot NSD_{r,b,s,y}}{AE_{r,b,s,1,f}}\right]} \quad \textbf{(B - 89)}$$

$$f \in \{\ MajorFuels\ \}$$

The third subscript of *DecAvgEff* represents the equipment decision type, *d*.

Average equipment efficiency for replacement decision type, by fuel, end-use, and Census division:

$$DecAvgEff_{r,s,2,f,y} = \frac{\sum_b [FS_{r,b,s,2,f} \cdot RSD_{r,b,s,y}]}{\sum_b \left[\frac{FS_{r,b,s,2,f} \cdot RSD_{r,b,s,y}}{AE_{r,b,s,2,f}}\right]}$$

(B - 90)

$$f \in \{MajorFuels\}$$

Average equipment efficiency for retrofit decision type, by fuel, end-use, and Census division:

$$DecAvgEff_{r,s,3,f,y} = \frac{\sum_b [FS_{r,b,s,3,f} \cdot SSD_{r,b,s,y}]}{\sum_b \left[\frac{FS_{r,b,s,3,f} \cdot SSD_{r,b,s,y}}{AE_{r,b,s,3,f}}\right]}$$

(B - 91)

$$f \in \{\ MajorFuels\ \}$$

Fuel shares within new decision type, by fuel, end-use, and Census division:

$$DecFuelShare_{r,s,1,f,y} = \frac{\sum_b [FS_{r,b,s,1,f} \cdot NSD_{r,b,s,y}]}{\sum_b NSD_{r,b,s,y}}$$ **(B - 92)**

$$f \in \{\ MajorFuels\ \}$$

The third subscript of *DecFuelShare* represents decision type, *d*.

Fuel shares within replacement decision type, by fuel, end-use, and Census division:

$$DecFuelShare_{r,s,2,f,y} = \frac{\sum_b [FS_{r,b,s,2,f} \cdot RSD_{r,b,s,y}]}{\sum_b RSD_{r,b,s,y}}$$ **(B - 93)**

$$f \in \{\ MajorFuels\ \}$$

Fuel shares within retrofit decision type, by fuel, end-use, and Census division:

$$DecFuelShare_{r,s,3,f,y} = \frac{\sum_{b} [\, FS_{r,b,s,3,f} \cdot SSD_{r,b,s,y} \,]}{\sum_{b} SSD_{r,b,s,y}} \qquad \textbf{(B - 94)}$$

$$f \in \{\ MajorFuels\ \}$$

National average equipment efficiency, by fuel and end-use:

$$CMUSAvgEff_{s,f,y} = \frac{\sum_{r}\sum_{b}\left\lfloor FuelShareofService_{r,b,s,f} \cdot TSD_{r,b,s,y} \right\rfloor}{\sum_{r}\sum_{b}\sum_{t,v}\left[\dfrac{TechShareofService_{r,b,s,t,v} \cdot FuelbyTech_{t,f} \cdot TSD_{r,b,s,y}}{TechEff_{r,s,t,v}}\right]} \qquad \textbf{(B - 95)}$$

$$s \in \{\ MajorServices\ \},\ f \in \{\ MajorFuels\ \}$$

Minor service average efficiency by fuel, end-use, building, and Census division:

$$AverageEfficiency_{r,b,s,f} = PrevYrAverageEfficiency_{r,b,s,f} \cdot (1 + EffGrowthRate_{s}\ ) \qquad \textbf{(B - 96)}$$

$$s \in \{\ MinorServices\ \},\ f = electricity$$

Minor service average efficiency and fuel share by decision type, fuel, end-use, and Census division:

$$DecAvgEff_{r,s,d,f,y} = AverageEfficiency_{r,b,s,1}$$

$$DecFuelShare_{r,s,d,f,y} = FuelShrofService_{r,b,s,1} \qquad \textbf{(B - 97)}$$

$$s \in \{\ MinorServices\ \}$$

Comparison of three-year average price to base year price for Price-induced Technological Change:

$$PriceDelta_{f,y} = \frac{(Price_{f,11,y} + Price_{f,11,y-1} + Price_{f,11,y-2}) \cdot 0.333}{Price_{f,11,Baseyear}} \quad \textbf{(B - 98)}$$

$$f \in \{MajorFuels\}; y > KSTEOYR$$

Where the subscript 11 represents region 11, resulting in the national average price for a given fuel.

Calculation of possible shift in technology availability for Price-Induced Technological Change:

$$Shiftyears_{t,v} = \frac{(PriceDelta_{f,y} - 1.0)}{0.10} \quad \textbf{(B - 99)}$$

$$f \in \{MajorFuels\}; y > KSTEOYR$$

Number of years to shift technology availability based on parameter assumptions for Price-Induced Technological Change:

$$YearsForward_{t,v,y} \equiv \begin{cases} IFMAX, & \text{if } IFMAX \le Shiftyears_{t,v} \\ ShiftYears_{t,v}, & \text{if } YearsForward_{t,v,y-1} < ShiftYears_{t,v} < IFMAX \\ YearsForward_{t,v,y-1}, & otherwise \end{cases} \quad \textbf{(B - 100)}$$

Where *IFMAX* is the user parameter specifying the maximum number of years a technology can potentially be advanced. *YearsForward* 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:

$$EndUseConsump_{f,s,b,r} = \frac{FuelShareofService_{r,b,s,f} \cdot TSD_{r,b,s,y}}{AverageEfficiency_{r,b,s,y}}, if \ AverageEfficiency > 0$$

(B - 101)

$$0, otherwise$$

$$s \neq lighting, \ f \in \{ \ MajorFuels \ \}$$

Basic estimate of fuel consumption by lighting equipment:

$$EndUseConsump_{f,s,b,r} = \frac{FuelShareofService_{r,b,s,f} \cdot TSD_{r,b,s,y}}{AverageEfficiency_{r,b,s,y}} \div 0.03343$$

(B - 102)

$$s = lighting$$

$$where\ 0.03343 \frac{GWY}{TBtu} converts\ units\ used\ in\ lighting\ to\ Btu\ units$$

The lighting units GWY refers to electricity use in Gigawatt-Years.

Short-run Price Elasticity of Demand Function:

$$KElast_{f,r,y,s} = \left(\frac{Pr_{f,r,y,s}}{Pr_{f,r,CBECSyear,s}} \right)^{\varepsilon_1 \cdot EF_1} \cdot \left(\frac{Pr_{f,r,y-1,s}}{Pr_{f,r,CBECSyear,s}} \right)^{\varepsilon_1 \cdot EF_2} \cdot \left(\frac{Pr_{f,r,y-2,s}}{Pr_{f,r,CBECSyear,s}} \right)^{\varepsilon_1 \cdot EF_3}$$

(B - 103)

$$f \in \{MajorFuels\}$$

Where $Pr_{f,r,y,s}$ 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:

$$EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} \cdot KElast_{f,r,y,s}$$

$$\cdot \left(1 + \left[1 - \frac{AverageEfficiency_{r,b,s,f}}{AverageEfficiencyBASE_{r,b,s,f}} \right] \cdot \varepsilon_2 \right)$$

$$\cdot \left(1 + \left[ShellEffIndex_{b,r,1} - 1 \right] \cdot \varepsilon_2 \right)$$

$f \in \{ MajorFuels \}$
$s \in \{ SpHeat + SpCool \}$

(B - 104)

evaluated without building shell effect (third term) for
$s \in \{$*water htg, ventilation, cooking, and lighting*$\}$
evaluated without equipment and building shell efficiency effects (second and third terms) for
$s \in \{$*refrigeration, all office equipment, and other uses*$\}$

Where ε_2 is the elasticity parameter for the rebound elasticity.

Weather Correction for space heating:

$$EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} \cdot \frac{DegreeDays_{s,r,y}}{DegreeDays_{s,r,CBECSyear}}$$

(B - 105)

$s \in \{ SpHeat \}$
$f \in \{ MajorFuels \}$

Weather Correction for space cooling:

$$EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} \cdot \left(\frac{DegreeDays_{s,r,y}}{DegreeDays_{s,r,CBECSyear}} \right)^{1.1}$$

(B - 106)

$s \in \{ SpCool \}$
$f \in \{ MajorFuels \}$

Computation of shares of electricity for end-use adjustment to purchased electricity to account for self-generation:

$$ElShr_s = \frac{EndUseConsump_{1,s,b,r,y}}{\sum_s EndUseConsump_{1,s,b,r,y}} \qquad \textbf{(B - 107)}$$

Where 1 is the fuel subscript representing electricity.

Deduction of electricity generated by distributed generation technologies other than PV from purchased electricity demand:

$$EndUseConsump_{1,s,b,r,y,} = EndUseConsump_{1,s,b,r,y,} - \sum_t Trills_{y,r,b,t} \cdot ElShr_s \qquad \textbf{(B - 108)}$$

$$t \neq 1, PV$$

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.

Deduction of electricity generated by distributed PV systems from purchased electricity demand:

$$EndUseConsump_{1,2,b,r,y,} = EndUseConsump_{1,2,b,r,y} - \frac{2}{3} \cdot Trills_{y,r,b,1}$$

$$EndUseConsump_{1,6,b,r,y,} = EndUseConsump_{1,6,b,r,y} - \frac{1}{6} \cdot Trills_{y,r,b,1} \qquad \textbf{(B - 109)}$$

$$EndUseConsump_{1,10,b,r,y,} = EndUseConsump_{1,10,b,r,y} - \frac{1}{6} \cdot Trills_{y,r,b,1}$$

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). Electricity generated by PV systems is assumed to primarily affect space cooling loads, with a lesser effect on lighting and miscellaneous end-use services.

Reduction in space and water heating consumption due to combined heat and power (CHP):

$$EndUseConsump_{f,1,b,r,y,} = EndUseConsump_{f,1,b,r,y,} - \sum SHBtu_{y,r,b,t}$$

$$EndUseConsump_{f,3,b,r,y,} = EndUseConsump_{f,3,b,r,y,} - \sum HWBtu_{y,r,b,t}$$

(B - 110)

$$\forall t \ \ using \ \ fuel \ \ f$$
$$f \ \in \{natural\ gas, distillate\}$$

Where $SHBtu_{y,r,b,t}$ 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-174 and 175).

Addition of Consumption of major fuels by distributed generation and CHP technologies:

$$EndUseConsump_{f,10,b,r,y,} = EndUseConsump_{f,10,b,r,y,} + \sum_{\forall t \ using \ fuel \ f} FuelUsage_{y,r,b,t}$$

(B - 111)

$$f \ \in \{natural\ gas, distillate\}$$

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-173).

Consumption of fuels to provide district services, by Census division, building type, fuel, and service:

$$DistServConsump_{r,b,s,f,y} = DistServSteamEUI_{r,b,s}$$

$$\cdot \ (SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y})$$

(B - 112)

$$\cdot \left(\frac{DistServFuelShr_{b,f}}{DistServBoilerEff_{f}} \right) \cdot 10^{-3}$$

$$s \in \{DistrictServices\}; \ f \in \{MajorFuels\}$$

Weather correction and short-term price elasticity for district services consumption:

$$DistServConsump_{r,b,s,f,y} = DistServConsump_{r,b,s,f,y} \cdot KElast_{f,r,y,s} \cdot \frac{DegreeDays_{s,r,y}}{DegreeDays_{s,r,CBECSyear}} \quad \textbf{(B - 113)}$$

$$s \in \{ SpHeat + SpCool \}$$
$$f \in \{ MajorFuels \}$$

$$evaluated\ without\ weather\ effect\ for\ s \in \{water\ htg\}$$

U.S. total fuel consumption to provide district services (quadrillion Btu):

$$CMUSDistServ_{s,f,y} = \left[\sum_r \sum_b DistServConsump_{r,b,s,f,y} \right] \cdot 10^{-3} \quad \textbf{(B - 114)}$$

$$s \in \{DistrictServices\};\ f \in \{MajorFuels\}$$

Addition of district services fuel use to end-use fuel consumption:

$$EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} + DistServConsump_{r,b,s,f,y} \quad \textbf{(B - 115)}$$

$$f \in \{MajorFuels\}$$

Total fuel consumption across end-use services:

$$FinalEndUseCon_{f,b,r,y} = \sum_s EndUseConsump_{f,s,b,r} \quad \textbf{(B - 116)}$$

$$f \in \{ MajorFuels \}$$

Unbenchmarked fuel consumption projection by Census division and building type:

$$UnBenchCon_{f,r,b,y} = FinalEndUseCon_{f,b,r,y}$$

$$f \in \{ \; MajorFuels \; \}$$

(B - 117)

U.S. total fuel consumption by end-use (quadrillion Btu):

$$CMUSConsump_{s,f,y} = \; [\sum_r \sum_b EndUseConsump_{f,s,b,r,y}] \cdot 10^{-3}$$

$$f \in \{ \; MajorFuels \; \}$$

(B - 118)

U.S. average minor service equipment efficiency by end-use and fuel:

$$CMUSAvgEff_{s,f,y} = \frac{\sum_r \sum_b [\; FuelShareofService_{r,b,s,f} \cdot TSD_{r,b,s,y} \;]}{CMUSConsump_{s,f,y} \cdot 10^{3}}$$

$$\forall s \in \{ \; MinorServices \; \}, \; f \in \{ \; MajorFuels \; \}$$

(B - 119)

Consumption of minor fuels - calculation of moving average:

$$FinalEndUseCon_{f,b,r,y} = \frac{\sum_{y'} \sum_b FinalEndUseCon_{f,b,r,y'}}{6}$$

$$f \in \{ \; MinorFuels \; \}, \; y - 6 \le y' \le y - 1$$

(B -120)

Modification of minor fuel consumption by Price Elasticity Effect:

$$FinalEndUseCon_{f,b,r,y} = \; FinalEndUseCon_{f,b,r,y} \cdot Price_{f,r,y}^{MinFuelBeta_{r,f-CMnumMajFl}}$$

$$f \in \{MinorFuels \; except \; coal \; and \; motor \; gasoline\}$$

(B - 121)

Adjustment of minor fuel consumption for floorspace growth:

$$FinalEndUseCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y} \cdot \frac{FinalEndUseCon_{f,b,r,y-1}}{\sum_{b} FinalEndUseCon_{f,b,r,y-1}} \cdot \frac{\left(SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y} \right)}{\left(SurvFloorTotal_{r,b,y-1} + CMNewFloorSpace_{r,b,y-1} \right)}$$

(B - 122)

$$f \in \{MinorFuels\ except\ coal\}$$

Unbenchmarked consumption of fuels across building types, by Census division:

$$CMFinalUnbenchCon_{f,r,y} = \sum_{b} UnBenchCon_{f,b,r,y}$$

(B - 123)

$$\forall\ f \in \{MajorFuels\}$$

Consumption of fuels across end-uses, including CHP and district services, by Census division:

$$CMFinalEndUse_{f,r,y} = \sum_{b} FinalEndUseCon_{f,b,r,y}$$

(B -124)

$$f \in \{\ MajorFuels + MinorFuels + RenewableFuels\ \}$$

U.S. total consumption by building type, across end-uses, including CHP, district services, and solar thermal:

$$CMFinalEndUseCon_{b,y} = \sum_{r} \sum_{f} FinalEndUseCon_{f,b,r,y}$$

$$\forall f \in \{MajorFuels + MinorFuels + RenewableFuels\}$$

$$CMFinalEndUseCon_{b,y} = \sum_{r} \sum_{f} FinalEndUseCon_{f,b,r,y} + \sum_{r} \sum_{s} \frac{SolarRenewableContrib_{r,s,y}}{CMnumBldg}$$

(B -125)

$$\forall s \in \{\ Space\ Htg + Water\ Htg\ \}$$

Benchmarking Equations

Difference between projection and SEDS fuel consumption data (“SEDS mistie”) for historical years:

$$SEDSMistie_{f,r,[y]} = CMSEDS_{f,r,y} - CMFinalEndUse_{f,r,y}$$

$$y \leq MSEDYR + 1 \qquad \textbf{(B - 126)}$$
$$f \in \{ MajorFuels + MinorFuels \}$$

The brackets around the year index indicate that *SEDSMistie* implicitly possesses a year dimension, although it is not explicitly declared as having one.

Non-building fuel use projection for historical years:

$$CMNonBldgUse_{f,r,y} = SEDSMistie_{f,r,[y]}$$

(B - 127)

$$y \leq MSEDYR + 1$$

Difference between projected electricity or natural gas use with SEDS non-building component, and STEO forecast:

$$STEOMistie_{f,r,[y]} = \left\langle CMSEDS_{f,r,y} - TranFromSEDS_{f,r,y} - NUGFromSEDS_{f,r,y} \right\rangle - \left\langle \begin{array}{l} CMFinalEndUse_{f,r,y} + SEDSMistie_{f,r,[MSEDYR+1]} \\ \quad + \left(\dfrac{MC\_COMMFLSP_{r,1,y} - MC\_COMMFLSP_{r,1,MSEDYR+1}}{MC\_COMMFLSP_{r,1,MSEDYR+1}} \right) \\ \quad \cdot \left| SEDSMistie_{f,r,[MSEDYR+1]} \right| \end{array} \right\rangle \qquad \textbf{(B - 128)}$$

$$MSEDYR + 1 < y \leq KSTEOYR$$
$$f \in \{ Electricity, Natural\ Gas \}$$

SEDS-based component of non-building fuel use of electricity or natural gas after last year of available SEDS data:

$$CMNonBldgUse_{f,r,y} = SEDSMistie_{f,r,[MSEDYR+1]} + \left(\frac{MC\_COMMFLSP_{r,1,y} - MC\_COMMFLSP_{r,1,MSEDYR+1}}{MC\_COMMFLSP_{r,1,MSEDYR+1}} \right) \cdot \left| SEDSMistie_{f,r,[MSEDYR+1]} \right| \qquad \textbf{(B - 129)}$$

$$y > MSEDYR + 1$$
$$f \in \{\ Electricity, Natural\ Gas\ \}$$

Projected electricity consumption for water services:

$$WaterSvcElQ_{r,y} = \left(MiscK3_{mc} \cdot \Delta y^3 + MiscK2_{mc} \cdot \Delta y^2 + MiscK1_{mc} \cdot \Delta y + MiscK0_{mc} \right) \cdot \frac{Pop_{r,y}}{Pop_{11,y}} \qquad \textbf{(B - 130)}$$

Where $\Delta y \equiv y - CBECSyear$, the number of years between the current year and the commercial base year, $Pop_{r,y}$ is the projected population in Census division r with r =11 representing U.S. total, and mc is the category index for water services within specified categories of "Other" end-use services. Values for equation coefficients and constants associated with each miscellaneous use category are provided in Appendix A.

Projected growth in electricity consumption for water services after last year of available SEDS data:

$$WaterSvcQGrowth_{[r],[y]} = WaterSvcElQ_{r,y} - WaterSvcElQ_{r,MSEDYR+1} \qquad \textbf{(B - 131)}$$

Addition of projected water services growth to SEDS-based component of non-building fuel use of electricity:

$$CMNonBldgUse_{1,r,y} = CMNonBldgUse_{1,r,y} + WaterSvcQGrowth_{[r],[y]} \qquad \textbf{(B - 132)}$$

Only growth in electricity use for water services is added because the SEDS-based component of non-building electricity consumption includes use for water services in the last year of available SEDS data.

Difference between projected distillate or minor fuel consumption with SEDS non-building component, and STEO forecast:

$$STEOMistie_{f,r,[y]} = (CMSEDS_{f,r,y} - TranFromSEDS_{f,r,y} - NUGFromSEDS_{f,r,y}) - (CMFinalEndUse_{f,r,y} + SEDSMistie_{f,r,[MSEDYR+1]})$$

(B - 133)

$$MSEDYR + 1 < y \leq KSTEOYR$$
$$f \in \{ \ Distillate, MinorFuels \ \}$$

SEDS-based component of non-building distillate or residual fuel consumption:

$$CMNonBldgUse_{f,r,y} = SEDSMistie_{f,r,[MSEDYR+1]}$$

(B - 134)

$$y > MSEDYR + 1$$
$$f \in \{ \ Distillate, MinorFuels \ \}$$

Limit STEO Benchmarking adjustments to cases where the STEOmistie is greater in absolute value than 2% of the STEO forecast

$$STEOMistie_{f,r,[y]} \equiv \begin{cases} 0.0, & if \ ABS(STEOMistie_{f,r,[y]}) \leq 0.02 \cdot CMSEDS_{f,r,y} \\ STEOMistie_{f,r,[y]} - 0.02 \cdot CMSEDS_{f,r,y}, & if \ STEOmistie_{f,r,[y]} > 0.02 \cdot CMSEDS_{f,r,y} \\ STEOMistie_{f,r,[y]} + 0.02 \cdot CMSEDS_{f,r,y}, & if \ STEOmistie_{f,r,[y]} < -0.02 \cdot CMSEDS_{f,r,y} \end{cases}$$

(B - 135)

$$MSEDYR + 1 < y \leq KSTEOYR$$

Optional benchmarking to STEO forecast for years where STEO data is available:

$$CMNonBldgUse_{f,r,y} = CMNonBldgUse_{f,r,y} + STEOMiostie_{f,r,[y]} \ ,$$

$$if \ STEOBM = 1 \ and \ ComSTEOBM = 1$$
$$unchanged \ , otherwise$$

(B - 136)

$$MSEDYR + 1 < y \leq KSTEOYR$$
$$f \in \{ \ Major \ and \ minor \ fuels \ \}$$

Optional decay factor to apply to final STEO mistie for optional benchmarking to STEO after last year of STEO data:

$$STEOTieDecayFactor_{[y]} \equiv \begin{cases} 1, & if \quad DecayBM = 0 \\ 1 - \dfrac{(\ y - KSTEOYR\ )}{(\ FirstNonBenchYr - KSTEOYR\ )}, & if \quad DecayBM = 1 \\ 0, & if \quad DecayBM = 1 \ and \\ & y \geq FirstNonBenchYr \end{cases} \quad \textbf{(B - 137)}$$

Where *FirstNonBenchYr* is converted from a calendar year to a year index prior to use. Decay factor is applied to all fuels for *AEO2007*.

Optional STEO-based component of non-building fuel consumption projected after last year of available STEO data:

$$\begin{aligned} CMNonBldgUse_{f,r,y} &= CMNonBldgUse_{f,r,y} \\ &+ STEOMistie_{f,r,[KSTEOYR]} \cdot STEOTieDecayFactor_{[\ y\ ]}\ , \\ &if\ \ STEOBM = 1; \\ &unchanged, otherwise \end{aligned} \quad \textbf{(B - 138)}$$

Final benchmarked projected fuel consumption by fuel, Census division, and year:

$$CMFinalEndUse_{f,r,y} = CMFinalEndUse_{f,r,y} + CMNonBldgUse_{f,r,y} \quad \textbf{(B - 139)}$$

$$f \in \{\ Major\ and\ minor\ \ fuels\ \}$$

Distributed Generation Equations

Distributed generation penetration is based on a cash flow simulation model. For each year in a NEMS run, a complete 30-year cash flow analysis is done for potential distributed generation investments. Simulations are carried out by Census division, building type and building size category for each of the currently available 10 distributed generation technologies modeled for the commercial sector. Each distributed generation technology, is further indexed by an annual "vintage" which aligns with the NEMS model year, and thus allows technical characteristics (like efficiency or cost) or tax incentives to vary continuously over the NEMS horizon. For ease of notation, the region, building type and size category subscripts will be suppressed until the interface with NEMS is described beginning with Equation B-170. Exceptions to the suppressing of regional and building type dimensions are made in a few instances before Equation B-170 for clarity. It is to be understood that in any given NEMS projection year, the total number of cash flow simulations performed will equal the number of Census divisions (9) times the number of modeled building types (11) times the number of building size categories (6) times the number of distributed technologies modeled (10). An uppercase Y is used to denote years in the cash flow analysis in order to distinguish cash flow simulation years from NEMS model years (which are denoted with a lowercase y). The annual technology vintages will also be denoted with lowercase y, since technology vintages "align" with NEMS projection years. Even though the cash flow model is run by region, building type and size category for each distributed generation technology and for each NEMS model year, many of the cash flow variables are only dimensioned by Y, the simulation year of the cash flow model itself. For such variables and also for those that accumulate by either y or Y, but not having an explicit year dimension, the convention of placing the 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 occurs. 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:

$$AdjCost_{t,[y]} = MIN\left\langle CapCost_{t,[y]}, C_{0,t} \cdot CumShip_{t,[y]}{}^{-\beta_t} \right\rangle \qquad \textbf{(B - 140)}$$

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 both residential and commercial buildings combined (supplied via the global interface).

Installed Equipment Cost:

$$EqCost_{t,[y]} = (AdjCost_{t,[y]} + InstCost_{t,[y]}) \cdot kW_{t,y} \qquad \textbf{(B - 141)}$$

Initial Outlay Cost:

$$DownPay_{[t],[y]} = EqCost_{t,[y]} \cdot DownPayPct \qquad \textbf{(B - 142)}$$

Annual levelized payment calculation:

$$Payment_{[t],[y]} = \left[EqCost_{t,[y]} - DownPay_{[t],[y]}\right] \cdot \frac{IntRate}{1-(1+IntRate)^{-Term}} \qquad \textbf{(B - 143)}$$

where the term in brackets is the amount financed, *IntRate* is the interest rate for the loan and *Term* is the number of years over which the loan payments are amortized.

Outlays for capital relating to down payments and borrowing costs:

$$\begin{aligned} &Outlay_{[t],[y],Y=1} = DownPay_{[t],[y]} \\ &Outlay_{[t],[y],1<Y\le Term} = Payment_{[t],[y]} \\ &Outlay_{[t],[y],Y>Term} = 0 \end{aligned} \qquad \textbf{(B - 144)}$$

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

$$\begin{aligned} &Prin_{[t],[y],Y} = Payment_{[t],[y]} - IntAmt_{[t],[y],Y} \\ &where \quad IntAmt_{[t],[y],Y} = IntRate \cdot LoanBal_{[t],[y],Y-1}, and \\ &\qquad 1 < Y \le Term \end{aligned} \qquad \textbf{(B - 145)}$$

$Prin_{[t],[y],Y}$ is the amount of principal paid on the loan in each year Y of the cash flow analysis and is also used to determine the loan balance for the next year of the analysis. It is computed as the difference between the levelized payment and the interest paid: $IntAmt_{[t],[y],Y}$ is the interest paid for the loan in each year of the analysis. This variable is a component of the tax deduction calculation. It is computed as last year's ending principal balance, $LoanBal_{[t],[y],Y-1}$, times the interest rate on the loan. $LoanBal_{[t],[y],Y}$ is the principal balance of the loan for each year of the analysis. The loan balance reduces over time according to the formula:

$$LoanBal_{[t],[y],Y} = LoanBal_{[t],[y],Y-1} - Prin_{[t],[y],Y} \qquad \textbf{(B - 146)}$$

$TaxCredit_{[t],[y],Y}$ is the allowed tax credit and can vary both by technology and vintage for distributed generation investments favored by the tax code. The credit is assumed to be collected in Year 3 of the cash flow analysis. Currently 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). EPACT05 increases the tax credit for photovoltaics to 30% for systems installed in 2006 and 2007. EPACT05 also provides a 30% tax credit for fuel cells (with a maximum of $500 per 0.5 kilowatt) and a 10% tax credit for microturbines (with a maximum of $200 per kilowatt) for systems installed in 2006 and 2007. EPACT92 provides for a shortened tax life of 5 years for photovoltaics (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.

$$TaxCredit_{[t],[y],Y} \equiv MAX\left\langle EqCost_{t,[y]} \cdot TaxCreditPct_{[t],[y]}, TxCreditMax_{[t],[y]}\right\rangle, \quad if\ Y=3, \qquad 0, \quad if\ Y \neq 3 \tag{B - 147}$$

$Depr_{[t],[y],Y}$ is the computed depreciation amount. Based on current tax law, the depreciation method is set to straight line for all technologies except PV, which is allowed accelerated depreciation using a "double-declining balance" formula with the $AccelFac_{[t],[y]}$ 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 $Depr_{[t],[y],Y}$ 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:

$$Depr_{[t],[y],Y} = \frac{\left(EqCost_{t,[y]} - 0.5 \cdot TaxCredit_{[t],[y]}\right)}{TaxLife_{[t],[y]}} \cdot kW_{t,y} \tag{B - 148}$$

Accelerated depreciation calculation:

$$Depr_{[t],[y],Y} = MAX\left\langle \frac{Basis_{[Y]}}{TaxLife_{[t],[y]}} \cdot \frac{AccelFac_{[t],[y]}}{100.}, \frac{\left(EqCost_{t,[y]} - 0.5 \cdot TaxCredit_{[t],[y]}\right)}{TaxLife_{[t],[y]}} \cdot kW_{t,y} \right\rangle \tag{B - 149}$$

where the $Basis_{[Y]}$ is calculated according to the following:

$$\begin{aligned} Basis_{[Y]} &= \left(EqCost_{t,[y]} - 0.5 \cdot TaxCredit_{[t],[y],2}\right) \cdot kw_{t,y} && for \quad Y=2 \\ Basis_{[Y]} &= Basis_{[Y-1]} - Depr_{[t],[y],Y} && for \quad Y \geq 3 \end{aligned} \tag{B - 150}$$

and $Tax\ Credit_{[t],[y]}$ is the minimum of the total credit less the credit claimed to date and $25,000.

The first term in Equation B-149 represents the accelerated depreciation amount and the second term, the straight line amount. There will be a "crossover" year 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-149 is further limited to be no greater than the remaining $Basis_{[Y]}$.

Annual kWh generated by technology:

$AnnualKWH_{[t],[y]}$ represents the base level of annual system kWh generation for a new system for the specific technology and vintage being analyzed. For photovoltaics (technology, t=1) annual generation is determined by system size, efficiency and solar availability as follows:

$$AnnualKWH_{[t=1],[y]} = \left(ElEff_{t=1,y} \cdot SolarIns_r \cdot ModuleSqft_y \cdot LossFac_{t=1,y}\right) \cdot kW_{t=1,y} \quad \textbf{(B - 151)}$$

The parenthetical expression represents the kWh generated by a 1-kW system, so this amount is then multiplied by system kW to yield the annual generation amount. Solar insolation, $SolarIns_r$, varies by Census division, and is expressed in annual kWh falling on a square foot area. The insolation value is then adjusted for module square footage and the electrical efficiency of the prototypical photovoltaic technology. Finally a loss factor (the percentage of the generation reaching the outlet) allows further adjustment of annual kWh available to the building by accounting for downstream electrical losses. The variable for the estimated PV array square footage for a 1-kW system, $ModuleSqft_y$, depends on the efficiency of the system and is computed based on a currently available 5-kW system with an electrical efficiency of 18% as follows:

$$ModuleSqft_y = \frac{346.78}{5.0} \cdot \frac{0.18}{ElEff_{1,v}} \quad \textbf{(B - 152)}$$

Note, that the higher the efficiency, the smaller the square footage that will be required for a 1-kW system. For non-solar technologies (t≠1), annual system generation for a 1-kW unit is determined by hours-of-use multiplied by an availability factor and a loss factor. Annual generation is determined by multiplying the amount for a 1-kW system by system capacity:

$$AnnualKWH_{[t],[y]} = \left(OperHours_t \cdot Avail_{t,y} \cdot LossFac_{t,y}\right) \cdot kW_{t,y} \quad \text{for } t \neq 1 \quad \textbf{(B - 153)}$$

$KWH_{[t],[y],Y}$ is the actual kWh generated in each of the years of the cash flow analysis. The actual generation is the ideal generation adjusted for degradation as the system ages. Currently, only photovoltaic generation has a non-zero degradation factor. Its value of 0.01 assumes a 1-percent per year loss in output as the modules age. Degradation begins in the year after the system is fully in use, which for the cash flow model assumptions is year 3.

$$KWH_{[t],[y],Y} = AnnualKWH_{[t],[y]} \cdot \left(1 - Degredation_{[t],[y]}\right)^{(Y-2)} \quad \textbf{(B - 154)}$$

Fuel consumption of fuel using distributed generation technologies:

Fuel consumption for "fired" generation technologies is denoted by the variable $FuelInput_{[t],[y]}$ and is calculated in MMBtu of the input fuel used by the technology:

$$FuelInput_{[t],[y]} = \frac{0.003412 \cdot OperHours_t \cdot Avail_{t,y}}{ElEff_{t,y}} \cdot kW_{t,y} \qquad \textbf{(B - 155)}$$

Calculation of waste heat available for water heating and space heating use:

$BTUWasteHeat_{[t],[y]}$ 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.

$$BTUWasteHeat_{[t],[y]} = \left(FuelInput_{[t],[y]} - .003412 \cdot AnnualKWH_{[t],[y]}\right) \cdot WhRecoveryEff_{t,y} \qquad \textbf{(B - 156)}$$

The amount of available waste heat is partitioned first into water heating and any residual into space heating end use services up to the average consumption for those end uses by Census division, building type (b) and size category (s):

$$\begin{aligned} &WaterHeatingMMBtu_{[t],[y]} = MIN\left\langle BTUWasteHeat_{[t],[y]}, AvgWaterHtgMMBtu_{[r],[b],[s]}\right\rangle \\ &where\ AvgWaterHtgMMBtu_{[r],[b],[s]} = AvgSqft_{b,s} \cdot ComEUI_{r,b,EU=WH,F=NaturalGas} \end{aligned} \qquad \textbf{(B - 157)}$$

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 be not utilized to offset end use fuel requirements.

$$\begin{aligned} &SpaceHeatingMMBtu_{[t],[y]} = \\ &\quad MIN\left\langle BtuWasteHeat_{[t],[y]} - WaterHeatingMMBtu_{[t],[y]}, AvgSpaceHtgMMBtu_{[r],[b],[s]}\right\rangle \\ &where\ AvgSpaceHtgMMBtu_{[r],[b],[s]} = AvgSqft_{b,s} \cdot ComEUI_{r,b,EU=SH,F=NaturalGas} \end{aligned} \qquad \textbf{(B - 158)}$$

Net fuel cost:

$BaseYrFuelCost_{[t],[y]}$ is the initial fuel costs for operating the generation technology net of savings stemming from displaced water heating or space heating. It is calculated from the current fuel price and fuel input and converted into the same year dollars as the technology capital costs (currently 2005 constant dollars).

$$BaseYrFuelCost_{[t],[y]} = \left(FuelInput_{[t],[y]} - WaterHtgMMBtu_{[t],[y]} - SpaceHeatingMMBtu_{[t],[y]}\right) \cdot FuelPrice_{r,y} \quad \textbf{(B - 159)}$$

$FuelCost_{[t],[y],Y}$ is the nominal dollar value fuel cost for the technology net of any water heating cost savings from using waste heat:

$$FuelCost_{[t],[y],Y} = BaseYrFuelCost_{[t],[y]} \cdot (1 + inflation)^{(Y-2)} \quad \textbf{(B - 160)}$$

The value of electricity savings calculations:

$ValElecSaveBase_{[t],[y]}$ 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, (i.e., $AnnualKWH_{[t],[y]} <= AvgKWH_b$), then savings are valued at the air conditioning price (since photovoltaic generation tends to correlate with the need for air conditioning):

$$ValElecSaveBase_{[t],[y]} = PelCMout_{r,y,AC} \cdot AnnualKWH_{[t],[y]} \cdot .003412 \quad \textbf{(B - 161)}$$

If generation exceeds average usage, then the excess kWh are sold to the grid at the marginal price for utility purchases ($PelME_{r,y}$) and the value is:

$$ValElecSaveBase_{[t],[y]} = .003412 \cdot \left[PelCMout_{r,y,AC} \cdot AvgKwh_{b,s} + PelME_{r,y} \cdot \left(AnnualKWH_{[t],[y]} - AvgKwh_{b,s}\right)\right] \quad \textbf{(B - 162)}$$

Case 2: All other technologies

The air conditioning price, $PelCMout_{r,y,AC}$, is replaced by $PelCM_{r,y}$, the average electricity price, in Equations B-161 and B-162.

$ValElecSave_{[t],[y],Y}$ is the nominal dollar (inflated) value of $ValElecSaveBase_{[t],[y]}$ with adjustment for output degradation:

$$ValElecSave_{[t],[y],Y} = ValElecSaveBase_{[t],[y]} \cdot (1 + inflation)^{(Y-2)} \cdot (1 - Degredation_{[t],[y]})^{(Y-2)} \quad \textbf{(B - 163)}$$

Maintenance cost calculations:

$MaintCost_{[t],[y],Y}$ is the calculated nominal dollar cost of maintenance for the specific technology and vintage being analyzed. $MaintCostBase_{[t],[y]}$ is the annual maintenance cost per kW and $IntervalCst_{[t=1],[y]}$ is the "interval" maintenance cost for inverter replacement per kW if the technology being evaluated is a photovoltaic system (i.e., technology index 1). $IntervalCst_{[t=1],[y]}$ is non-zero only if the cash flow model year, Y, is an inverter replacement year based on the replacement interval for photovoltaic system vintage, y.

$$MaintCost_{[t],[y],Y} = kW_{[t],[y]} \cdot \left[MaintCostBase_{[t],[y]} + IntervalCst_{[t=1,[y]} \right] \cdot (1 + inflation)^{(Y-2)} \quad \textbf{(B - 164)}$$

Deductible expenses for commercial income taxes:

$$TaxDeduct_{[t],[y],Y} = \begin{pmatrix} IntAmt_{[t],[y],Y-1} - Depr_{[t],[y],Y-1} - MaintCost_{[t],[y],Y-1} + \\ FuelCost_{[t],[y],Y-1} - ValElecSave_{[t],[y],Y-1} \end{pmatrix} \cdot TaxRate + TaxCredit_{[t],[y],Y} \quad \textbf{(B - 165)}$$

Cash flow and investment payback years:

$NetCashFlow_{[t],[y],Y}$, $CumCashFlow_{[t],[y],Y}$ and $SimplePayback_{[t],[y]}$ years:

$$NetCashFlow_{[t],[y],Y} = ValElecSave_{[t],[y],Y} + TaxDeduct_{[t],[y],Y} - OutLay_{[t],[y],Y} - FuelCost_{[t],[y],Y} - MaintCost_{[t],[y],Y} \quad \textbf{(B - 166)}$$

$CumCashFlow_{[t],[y],Y}$ is defined as the accumulated sum of all prior $NetCashFlow_{[t],[y],Y}$ amounts.

Simple payback years:

$SimplePayback_{[t],[y]}$ is defined as the first year in the cashflow stream for which an investment has a positive $CumCashFlow_{[t],[y],Y}$ (i.e., the "Y" if and when $CumCashFlow_{[t],[y],Y}$ first becomes greater than or equal to 0). Note that $SimplePayback_{[t],[y]}$ is stored as a real (floating point) number and not rounded off to "whole" years – this will affect the calculated maximum penetration of technology as described below.

Real-valued simple payback calculation:

Let Y' be the integer-valued year in the 30-year cash flow simulation for which $CumCashFlow_{[t],[y],Y'}$ achieves a non-negative value. Call this value $IntSimplePayback_{[t],[y]}$ to represent the integer-valued payback. The real-valued $SimplePayback_{[t],[y]}$ for this technology is interpolated as follows:

$$SimplePayback_{[t],[y]} = IntSimplePayback_{[t],[y]} - \frac{CumCashFlow_{[t],[y],Y'-1} + NetCashFlow_{[t],[y],Y'}}{NetCashFlow_{[t],[y],Y'}} \quad \textbf{(B - 167)}$$

Since Y' is the first year for which $CumCashFlow_{[t],[y],Y}$ is greater than or equal to zero, its prior year value (in year Y'-1) was less than zero. If $CumCashFlow_{[t],[y],Y'-1}$ was small in absolute value relative to $NetCashFlow_{[t],[y],Y'}$, then the right hand term would approach unity, which is the same as saying that the payback was achieved close to the beginning of Y'.

Maximum penetration into new construction:

$$MaxPen_{[t],[y]} = \frac{PenParm_t}{SimplePayback_{[t],[y]}} \quad \textbf{(B - 168)}$$

$PenParm_t$ is set to 0.3 for solar photovoltaics and natural gas-fired technologies. Thus the asymptotically approached $MaxPen_{[t],[y]}$ for these technologies with a 1-year payback will be 30%. Since $SimplePayback_{[t],[y]}$ is a real-valued number, it can potentially achieve values of less than one. For a $SimplePayback_{[t],[y]}$ of 0.5 years, $MaxPen_{[t],[y]}$ is 60%.

Penetration function formula for new construction:

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

$$Pen_{[t],[y]} = MaxPen_{[t],[y]} - \frac{1}{\frac{1}{MaxPen_{[t],[y]}} + e^{\left[\alpha_t \cdot \left(y - CogHistYear - SimplePayBack_{[t],[y]}\right)\right]}} \quad \textbf{(B - 169)}$$

$Pen_{[t],[y]}$ is constrained to a maximum penetration of 75% into new construction.

Penetration function formula for existing construction:

Penetration of distributed generation into the surviving (existing) stock of floorspace is further limited to a maximum of 0.5% or one-fiftieth of the penetration into new construction, whichever is less. It is denoted by $DeltaPen_{[t],[y]}$.

Outputs to the Commercial Module and NEMS:

Explicit recognition of the Census division and building type dimension commences here. $Units_{y,r,b,t}$ denote the accumulated total units in NEMS model year y employing the relevant type of generation technology by Census division and building type and is the sum of $Units_{y-1,r,b,t}$ plus penetration into new construction plus penetration into existing (surviving buildings) for the current NEMS model year plus 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:

$$Units_{y,r,b,t} = Units_{y-1,r,b,t} + \left(ExogPen_{y,r,t} - ExogPen_{y-1,r,t}\right) \cdot BldShr_{b,t} + \sum_{s} \left[\begin{array}{l} Pen_{r,b,s,t,y} \cdot CMNewFloorSpace_{r,b,y} \cdot CBECS03FlspcCatShare_{b,s} \cdot \dfrac{10^3}{AvgSqft_{b,s}} + \\ DeltaPen_{r,b,s,t,y} \cdot SurvFloorTotal_{r,b,y} \cdot CBECS03FlspcCatShare_{b,s} \cdot \dfrac{10^3}{AvgSqft_{b,s}} \end{array} \right] \quad \textbf{(B - 170)}$$

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

$$Trills_{y,r,b,t} = Trills_{y-1,r,b,t} + \sum_{s} \left[\begin{array}{l} \left(Units_{y,r,b,t} - Units_{y-1,r,b,t}\right) \cdot CBECS03FlspcCatShare_{b,s} \\ \cdot AnnualKWH_{[t],[y]} \cdot 3412 \cdot 10^{-12} \end{array} \right] \quad \textbf{(B - 171)}$$

$TrillsOwnUse_{y,r,b,t}$ accumulates total electricity generation for on-site 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.

$$TrillsOwnUse_{y,r,b,t} = TrillsOwnUse_{y-1,r,b,t} + \sum_{s} \left[\begin{array}{l} \left(Units_{y,r,b,t} - Units_{y-1,r,b,t}\right) \cdot CBECS03FlspcCatShare_{b,s} \\ \cdot MAX \left\langle AnnualKWH_{[t],[y]}, AvgKwh_{b,s} \right\rangle \cdot 3412 \cdot 10^{-12} \end{array} \right] \quad \textbf{(B - 172)}$$

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

$$FuelUsage_{y,r,b,t} = \sum_s \left[\begin{array}{l} \left(Units_{y,r,b,t} - Units_{y-1,r,b,t}\right) \cdot CBECS03FlspcCatShare_{b,s} \\ \cdot FuelInput_{[r],[b],[s],[t],[y]} \cdot 10^{-6} \end{array} \right] \quad \textbf{(B - 173)}$$

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

$$HWBtu_{t,y} = \sum_s \left[\begin{array}{l} \left(Units_{y,r,b,t} - Units_{y-1,r,b,t}\right) \cdot CBECS03FlspcCatShare_{b,s} \\ \cdot WaterHtgMMBtu_{[r],[b],[s],[t],[y]} \cdot 10^{-6} \end{array} \right] \quad \textbf{(B - 174)}$$

$SHBtu_{y,r,b,t}$ accumulates $SpaceHtgMMBtu_{[r],[b],[t],[y]}$ and converts to trillions of Btu:

$$SHBtu_{r,b,t,y} = \sum_s \left[\begin{array}{l} \left(Units_{y,r,b,t} - Units_{y-1,r,b,t}\right) \cdot CBECS03FlspcCatShare_{b,s} \\ \cdot SpaceHeatingMMBtu_{[r],[b],[s],[t],[y]} \cdot 10^{-6} \end{array} \right] \quad \textbf{(B - 175)}$$

$Invest_{y,r,b,t}$ is the current year investment in distributed generation resources in millions of 2005$:

$$Invest_{y,r,b,t} = \left(Units_{y,r,b,t} - Units_{y-1,r,b,t}\right) \cdot EqCost_{[t],[y]} \cdot kw_t \cdot 10^{-6} \quad \textbf{(B - 176)}$$

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 Commercial Module. 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.

"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 Arthur D. Little, Inc., "Determination of Typical Commercial Building Shell U-Values," draft report prepared for EIA under Contract No. DE-AC01-98EI34585,Washington, DC, August 1998.

Decision Analysis Corporation of Virginia and 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.

Electric Power Research Institute, A Compendium of Utility-Sponsored Energy Efficiency Rebate Programs, 1987.

Electric Power Research Institute, Commercial End-Use Data Development Handbook: COMMEND Market Profiles and Parameters, Vol. 2: COMMEND Data and Parameter Development Techniques, Regional Economic Research, Inc., EM-5703, San Diego CA, April 1988.

Discovery Insights, LLC, FINAL REPORT Commercial and Industrial CHP Technology Cost and Performance Data Analysis for EIA's NEMS, prepared for U.S. Department of Energy, Energy Information Administration, Bethesda MD, February 2006.

Energy Information Administration, U.S. Department of Energy, 2003 Commercial Buildings Energy Consumption Survey, Public Use Data Files, Washington DC, as of August 2006, web site www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html .

Energy Information Administration, U.S. Department of Energy, 1999 Commercial Buildings Energy Consumption Survey, Public Use Data Files, Washington DC, October 2002, web site www.eia.doe.gov/emeu/cbecs/1999publicuse/99microdat.html .

Energy Information Administration, U.S. Department of Energy, 1995 Commercial Buildings Energy Consumption Survey, Public Use Data Files, Washington DC, October 1998, web site www.eia.doe.gov/emeu/cbecs/contents.html .

Energy Information Administration, U.S. Department of Energy, A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures, DOE/EIA-0625(95), Washington DC, October 1998.

Energy Information Administration, U.S. Department of Energy, Commercial Buildings Characteristics 1992, DOE/EIA-0246(92), Washington DC, April 1994.

Energy Information Administration, U.S. Department of Energy, Commercial Buildings Consumption and Expenditures 1992, DOE/EIA-0318(92), Washington DC, April 1995.

Energy Information Administration, U.S. Department of Energy, Characteristics of Commercial Buildings 1989, DOE/EIA-0246(89), Washington DC, June 1991.

Energy Information Administration, U.S. Department of Energy, Commercial Buildings Consumption and Expenditures 1986, DOE/EIA-0318(86), Washington DC, May 1989.

Energy Information Administration, U.S. Department of Energy, "Estimation of Energy End-Use Intensities," Washington DC, November 1999, web site www.eia.doe.gov/emeu/cbecs/tech_end_use.html .

Energy Information Administration, U.S. Department of Energy, Lighting in Commercial Buildings, Washington DC, March 1992.

Energy Information Administration, U.S. Department of Energy, "Nonutility Power Producers," Electric Power Monthly, April 1992.

Energy Information Administration, U.S. Department of Energy, State Energy Consumption, Price, and Expenditure Estimates, Washington DC, as of August 2006, web site www.eia.doe.gov/emeu/states/_seds.html .

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.

Jackson, J. et al, The Commercial Demand for Energy: A Disaggregated Approach, Oak Ridge National Laboratory, April 1978.

Kawamoto, K. et al, Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendices, Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, Prepared for DOE, Contract No. DE-AC03-76SF00098, Berkeley CA, February 2001.

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.

Lamarre, L., "Shaping DSM," EPRI Journal, October/November 1991.

Lamarre, L., "New Push for Energy Efficiency," EPRI Journal, April/May 1990.

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.

Navigant Consulting, Inc., EIA - Technology Forecast Updates - Residential and Commercial Building Technologies, Reference No. 117934, prepared for U.S. Department of Energy, Energy Information Administration, September 2004.

Navigant Consulting, Inc., EIA - Technology Forecast Updates - Residential and Commercial Building Technologies Residential and commercial lighting, commercial refrigeration, and commercial ventilation technologies, Reference No. 40222, prepared for U.S. Department of Energy, Energy Information Administration, January 2006.

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.

Solar Energy Industries Association, Our Solar Power Future – The U.S. Photovoltaic Industry Roadmap through 2030 and Beyond, SEIA, September 2004.

Temple, Barker and Sloane, Inc., Xenergy, Inc., Market Research on Demand-Side Management Programs, EPRI EM-5252, Palo Alto CA: EPRI, June 1987.

TIAX, LLC, Commercial and Residential Sector Miscellaneous Electricity Consumption: Y2005 and Projections to 2030, Reference No. D0366, prepared for U.S. Department of Energy, Energy Information Administration, September 2006.

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. Environmental Protection Agency, "Green Lights Financing Directory Database," Version 2.0, January 1992.

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.

Z, Inc., TPL Codebook for 1986 Consumption and Expenditures Tables, NBECS 86, Z, Inc., Contract No. DE-AC01-85EI19693, Silver Spring MD, April 1989.

Appendix D. Model Abstract

Introduction

This section gives a brief summary of the Commercial Sector Demand Model and its role within the National Energy Modeling System. 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 Sector Demand Model

Model Acronym:

None

Description:

The NEMS Commercial Sector Demand Module is a simulation tool based upon economic and engineering relationships that models commercial sector energy demands at the nine Census division level of detail for eleven distinct categories of commercial buildings. Commercial equipment selections are performed for the major fuels of electricity, natural gas, and distillate fuel, for the major services of 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 minor fuels of residual oil, liquefied petroleum gas, steam coal, motor gasoline, and kerosene, the renewable fuel sources of wood and municipal solid waste, and the minor services of office equipment (with a separate breakout of personal computers), and "other" in less detail than the major fuels and 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 the National Energy Modeling System, the NEMS Commercial Module generates mid-term projections of commercial sector energy demand. The model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact commercial sector energy demand.

Most Recent Model Update:

November 2006.

Part of Another Model?

National Energy Modeling System (NEMS)

Model Interfaces:

Receives inputs from the Electricity Market Module, Natural Gas Transmission and Distribution Module, Petroleum Market Module, Coal Market Module, and Macroeconomic Activity Module within NEMS. Outputs are provided to the Electricity Market Module, Natural Gas Transmission and Distribution Module, Petroleum Market Module, Coal Market Module, and Integrating Module.

Official Model Representative:

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Documentation:

Energy Information Administration, U.S. Department of Energy, *Model Documentation Report: Commercial Sector Demand Model of the National Energy Modeling System*, DOE/EIA-M066(2007) (Washington, D.C., April 2007).

Archive Media and Installation Manual(s):

The Module, as part of the NEMS system, has been archived for the reference case published in the *Annual Energy Outlook 2007*, DOE/EIA-0581 (2007). The NEMS archive contains all of the nonproprietary modules of NEMS as used in the reference case. The NEMS archive is available on an as-is basis (ftp://eia.doe.gov/pub/oiaf/aeo/aeo2007.zip).

Energy System Described:

Domestic commercial sector energy consumption.

Coverage:

- Geographic: Nine Census divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific
- Time Unit/Frequency: Annual through 2030
- Products: Electricity, natural gas, distillate, residual oil, liquefied petroleum gas, coal, motor gasoline, kerosene, wood, municipal solid waste
- Economic Sectors: Eleven Building Categories: Assembly, Education, Food Sales, Food Services, Health Care, Lodging, Large Office, Small Office, Mercantile & Service, Warehouse, Other. Ten Services: Space Heating, Space Cooling, Water Heating, Ventilation, Cooking, Lighting, Refrigeration, PC-Related Office Equipment, NonPC-Related Office Equipment, Other.

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. Commercial Buildings Energy Consumption Survey 1995 and 1999 data are used for initial floorspace, market shares, fuel shares, district service shares. Engineering analyses used for initial efficiency estimates
- Special Features: Technology choice data base and simulation technique is capable of accommodating an extensive range of policy analyses, including but not limited to demand-side management capital incentives, tax credits, and equipment efficiency standards.

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 (O&M) cost, expected physical lifetime
- Equipment research and development (R&D) advances and projected dates of introduction
- Base year floorspace by Census division, building type, building age cohort, energy-consuming characteristics
- Base year district service consumption totals and relative shares
- Base year Energy Use Intensity (EUI) 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
- Current outlook for commercial sector generating capacity, to determine planned and unplanned additions to capacity
- 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, behavioral parameters.

Non-DOE Input Sources:

F.W. Dodge

- Description of floorspace categorization to enable mapping to DOE sources
- Non-residential building construction starts for development of building survival parameters

Arthur D. Little Technical Reports, EPRI Technical Assessment Guide, GRI Baseline Data Book, Navigant Consulting, Inc. 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 (O&M) cost, expected physical lifetime, based on data from the years 1990-2005
- Equipment research and development (R&D) advances and projected dates of model introduction, projections for technology availability encompassing the years 2005-2030.

DOE Input Sources:

Commercial Building Energy Consumption Survey(CBECS) , 2003 characteristics and building-level consumption, 1995 end-use energy consumption

- Base year floorspace by Census division, building type, building age cohort, energy-consuming characteristics
- Base year district service consumption totals and relative shares
- Base year Energy Use Intensity (EUI) 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

Form EI-860: Annual Electric Generator Report forms for years 2004 - 2005

- 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

Discovery Insights, LLC 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 (O&M) cost, expected physical lifetime
- Equipment research and development (R&D) advances and projected dates of model introduction, projections for technology availability encompassing the years 2006-2030.

Computing Environment:

- Hardware Used: HP Proliant Multiprocessor Server
- Operating System: Windows Server 2003, Standard Edition with MKS Toolkit UNIX emulation
- Language/Software Used: Intel Visual Fortran, Version 9
- Memory Requirement: 4,000K
- Storage Requirement: 88.5 Megabytes
- Estimated Run Time: 026 seconds for a 1990-2030 run in non-iterating NEMS mode
- Special Features: None.

Independent Expert Reviews Conducted:

Independent Expert Reviews of *Commercial Sector Component Design Report*, July 31, 1992 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.

Status of Evaluation Efforts by Sponsor:

None.

Appendix E. Data Quality

Introduction

The NEMS Commercial Sector Demand Module develops projections of commercial sector energy consumption based upon 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 model 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 Module projections of energy consumption. This section discusses the quality of the 2003 CBECS data set as described in *Survey Background & Technical Information*[40] on EIA's web site. Comparable information for the 1999 CBECS is available in *Technical Information on CBECS*[41]

CBECS Implementation.

EIA conducts the CBECS survey to provide basic statistical information on consumption of, and expenditures for, energy in U.S. commercial buildings, along with data on energy related characteristics of these buildings. CBECS is based upon a sample of commercial buildings selected according to the sample design for the 2003 CBECS described in Technical Information on CBECS.[42]

The CBECS methodology consists of two data-collection stages. In the first stage, information about the selected buildings is collected in the Buildings Characteristics Survey through voluntary personal interviews with the buildings' owners, managers, or tenants. The data are collected using Computer-Assisted Personal Interviewing (CAPI) techniques. Building energy consumption records are provided through the use of an Authorization Form to release this confidential data. In the second stage, the Energy Suppliers Survey, data concerning the actual consumption of energy is obtained through a mail survey conducted by a survey research firm under EIA's mandatory data collection authority. For the 2003 CBECS, the Energy Suppliers

[40] Energy Information Administration, *Survey Background & Technical Information*, see the Energy Information Administration web site at www.eia.doe.gov/emeu/cbecs/background.html.

[41] Energy Information Administration, *Technical Information on CBECS*, see the Energy Information Administration web site at www.eia.doe.gov/emeu/cbecs/technical_information.html.

[42] Ibid.

Survey was initiated only if the respondents to the Buildings Characteristics Survey could not provide the consumption and expenditures information.

The 2003 CBECS samples 6,955 buildings, selected based upon a multistage area probability sample supplemented by lists of large buildings and special buildings. A subsampling of establishments within strip shopping centers and enclosed malls is included with separate interviews conducted within these establishments. The Technical Information on CBECS source previously cited provides additional detail regarding the area probability sampling methodology. The 2003 CBECS is the first CBECS since 1986 to be collected under a new sample design.

Target Population

The target population of the 2003 CBECS is all commercial buildings in the United States that were larger than 1,000 ft^2 in area. All buildings in the sample satisfy three criteria: 1) each meets the size criteria described above, 2) each meets the survey definition of a "building", and 3) each is used primarily for commercial purposes. Building eligibility is evaluated at multiple points throughout the survey purpose to ensure data accuracy and quality.

Response Rates

The total sample of the 2003 CBECS is 6,955 buildings, comprised of 6,120 from the area sample frame and 835 from the special list frames. Of these 6,955 buildings, 6,380 were found eligible for interviewing. For establishments within malls, a sample of 880 was selected, comprised of 768 establishments from the area sample and 112 from the list sample. All of these establishments were found eligible for interviewing. Successful interviews for 82% of the eligible buildings (5,215) are contained in the 2003 CBECS, 4,683 from the area sample and 532 from the special list samples. Data for the 2003 CBECS also includes successful interviews for 76% of the mall establishments (668).

Data Collection

As previously described, the Buildings Characteristics Survey consists of personal interviews with buildings' owners, managers, and tenants. Data was collected using Computer-Assisted Personal Interviewing (CAPI) techniques. The six phases of data collection include: (1) designing the questionnaire, (2) pretesting the questionnaire, (3) training supervisors and interviewers, (4) conducting interview, (5) minimizing nonresponse, and (6) processing the data.

The Interview Process

Each interview includes an initial screening visit to verify building eligibility, list establishments in the case of shopping malls, locate a knowledgeable respondent for the interview, and leave an advance package of survey materials. The interviewer returns to conduct the CBECS interview at a set appointment time, after allowing time for the respondent to complete the advance materials. For buildings that can not provide the energy consumption and expenditures information, authorization forms are requested to permit the survey contractor to contact the energy supplier for that information. All survey data are collected by contractor field staff trained in data collection, field office procedures, and quality control. This training includes background information on the CBECS, handling of special building types and understanding technical questions, computer use and interviewing and administering the CAPI questionnaire, specific review of the questionnaire, and administrative information. This information is supplemented by general information on interviewing techniques for new interviewers.

Validation is used to ensure that the interviews are conducted as intended, with ten percent of the sample preselected for validation. Conducted by telephone or in person, validation includes verifying that the interview has been conducted, the correct building was visited, and specified procedures have been followed. Additional detail on these procedures is provided in the report previously cited.

Data Quality Verification

As a part of the input and editing procedure, an extensive program of edits and verifications was used, including:

- Energy range and skip checks based on previous CBECS responses and on knowledge of utility rates and practices;
- Consistency checks;
- Technical edits to detect and correct errors regarding length of billing periods, extreme variability, and reporting either consumption or expenditures - but not both.

This process ensures the quality of the 2003 CBECS input data, which is the principal source of initial floorspace levels and age cohorts, appliance stock composition, district service shares, and unbenchmarked 2003 end-use consumption.

Energy Use Intensity (EUI) Data Source

The EUI estimates discussed in Appendix A of this report (referenced in Table A-1) are based upon data provided in the 2003 CBECS and the 1995 CBECS Public Use Data. As discussed in Appendix A, building-level energy use estimates for the 2003 CBECS were available, however, energy end-use intensity estimates for the 2003 CBECS were not available for *AEO2007*. The data for the 1995 CBECS are Statistically Adjusted Engineering (SAE) estimates based upon survey data collected in the 1995 CBECS and building energy simulations provided by the Facility Energy Decision Screening (FEDS) system. The methodology used to obtain the final 1995 end-use estimates and data quality issues are addressed in *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures 1995*. For *AEO2007*, the 1995 EUI estimates were adjusted to the 2003 CBECS building-level consumption estimates. The results were then adjusted to account for equipment replacement, new construction, changes in operating hours, and weather differences between 1995 and 2003, using CBECS building characteristics data and the National Oceanic and Atmospheric Administration weather data discussed in Appendix A in the description for Heating and Cooling Degree Days.

Technology Characterization Data Sources

The Navigant Consulting, Discovery Insight and DAC data sources used to develop technology characterization profiles for the NEMS Commercial Module do not provide discussions of data quality.

Historical Energy Consumption Data: State Energy Data System (SEDS), 2001

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 upon availability, applicability, continuity, and consistency. These general considerations, along with the fuel-specific considerations discussed in the SEDS documentation[43] 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 Module are the initial proportions of commercial consumers that behave according to each of the seven risk-adjusted time preference premium segments and 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 are available to align model results with observed historical consumption results and professional expectations.

The initial behavior rule proportions are estimated by building type and decision type in order 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 decisionmaking 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 listed by decision type are provided in Table E-4. Data quality analysis was not performed in the data sources providing this information.

Risk-Adjusted Time Preference Premium Distribution

The literature surveyed provides five quantified distributions of commercial sector consumer payback requirements. These show considerable variation, which reflect 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 Module.

Insufficient studies are available to disaggregate consumer discount rates by Census division or by end use. As documented in the published data sources, the variance of each estimate was far

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[43]U.S. Department of Energy, Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates, Technical Notes, October 2006, Section 1: Documentation Guide available at http://www.eia.doe.gov/emeu/states/_seds_tech_notes.html.

greater than the difference between the studies by end use or region. Therefore, a single distribution is applied 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 eleven 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 bond 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 since they represented, in general, the utilities' estimates of commercial consumer discount rates, rather than specific statistical studies.

Since each risk-adjusted time preference segment requires computations for all of the relevant technologies as well as consuming memory storage locations, the number of risk-adjusted time preference premium categories has direct effects on both model run time and memory requirements. Initially, for AEO 1994 the eleven risk-adjusted time preference premium categories corresponding with payback requirements of 0 through 10 years were modeled. For AEO 1995, the number of categories was reduced to six, significantly reducing commercial model 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 (e.g., having explicitly modeled technologies) as well as by model year to allow potentially different values by end use and over time.[44] Generally, each end use and model year have had the same risk-adjusted time preference premium distributions and values; exceptions having been made in order to simulate programs promoting efficient equipment such as EPA's former Green Lights program, and the Energy Star Buildings program. For AEO 2000, a 7th 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, also known as the "Greening of Government" executive order. The risk-adjusted time preference premium distribution is currently modeled as follows:

[44] Expanding the dimensions of the distributions had virtually no impact on the Commercial Module run time and memory requirements, since each modeled technology choice still only involved calculations for only 6 time preference premiums.

Table E-1. Consumer Risk-adjusted Time Preference Premium Distribution

Percent of Commercial Sector Consumers	Commercial Consumers' Time Preference Premium to the Risk-Free Interest Rate
27.0 %	∞ (represented by 1000 %)
25.4 %	152.9 %
20.4 %	55.4 %
16.2 %	30.9 %
10.0 %	19.9 %
0.8 %	13.6 %
0.2%	0.0%

The proportions of commercial sector consumers given in **Table E-1** represent all end-use services except lighting. In order to model the effects of targeted voluntary energy efficiency programs for lighting, 8.5 percent of consumers are assumed to be in the 19.9 % premium category, 2.3 percent of consumers are assumed to have a 13.6 % premium and 0.2 percent of consumers are assumed to have a 0.0% premium.

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.

- 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.

DAC and 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 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)	Percent of Respondents (N=659)	Implied Real Internal Rate of Return (Percent)
1	17	161.8
2	17	64.0
3	18	39.3
4	6	28.3
>4 *	10	19.8
Don't Know **	33	∞

* Assumes that > 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 Period (years)	Cumulative Percent of Consumers with Payback Requirement			
	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 SAIC, "Alternative Methodologies for NEMS Building Sector Model Development," draft report, prepared under Contract No. DE-AC01-92EI21946, August 3, 1992, p. 14.

Table E-4. Floorspace Ownership and Occupancy Patterns

Building Type	Government Owned (percent)	Non-government Owner Occupied (percent)	Non-government Non-owner Occupied (percent)
Assembly	23.0 %	73.1 %	3.8 %
Education	67.3 %	31.0 %	1.7 %
Food Sales	0.0 %	83.3 %	16.7 %
Food Service	5.7 %	83.4 %	10.9 %
Health Care	27.0 %	71.1 %	1.9 %
Lodging	9.7 %	82.4 %	8.0 %
Mercantile/Service	6.8 %	64.5 %	28.6 %
Office	12.3 %	65.8 %	21.9 %
Warehouse	7.6 %	64.0 %	28.4 %
Other	33.4 %	61.8 %	4.7 %
TOTAL:	20.5 %	63.0 %	16.5 %

References

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, D.C., 1987.

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.

Office of Technology Assessment, *Building Energy Efficiency*, OTS-E-518, U.S. Government Printing Office, Washington, D.C., 1992.

U.S. Department of Energy, Energy Information Administration, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*, DOE/EIA-0625(95), October 1998.

U.S. Department of Energy, Energy Information Administration, *State Energy Data Report 1999, Consumption Estimates*, DOE/EIA-0214(99), May 2001.

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