

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

December 2000

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

## **UPDATE INFORMATION**

This updated version of the NEMS Commercial Module Documentation includes changes made to the commercial module for the production of the *Annual Energy Outlook 2001*.

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

December 2000

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

This report was prepared by the Energy Information Administration, the independent statistical and analytical agency within the Department of Energy. The information contained herein should be attributed to the Energy Information Administration and should not be construed as advocating or reflecting any policy position of the Department of Energy or of any other organization.

## Contents

1. Introduction .....	1
Purpose of this Report .....	1
Model Summary .....	1
Organization of this Report .....	2
2. Model Purpose .....	4
Model Objectives .....	4
Model Input and Output .....	5
Relationship of the Commercial Module to Other NEMS Modules .....	10
3. Model Rationale .....	13
Theoretical Approach .....	13
Fundamental Assumptions .....	14
Alternative Approaches .....	15
4. Model Structure .....	41
Key Computations and Equations .....	58

## Appendices

A. Input Data and Variable Descriptions .....	A-1
B. Mathematical Description .....	B-1
C. References .....	C-1
D. Model Abstract .....	D-1
E. Data Quality .....	E-1

# Tables and Figures

## Tables

Table 1. Dimensions Spanned by Commercial Module Variables . . . . .	9
Table 2. BEEM and NEMS Commercial Models: Conceptual Tasks . . . . .	17
Table 3. COMMEND and NEMS Commercial Models: Conceptual Tasks . . . . .	23
Table 4. ORNL and NEMS Commercial Models: Conceptual Tasks . . . . .	27
Table 5. CEDMS and NEMS Commercial Models: Conceptual Tasks . . . . .	30
Table 6. CBEF Variable Classification . . . . .	32
Table 7. CBEF and NEMS Commercial Models: Conceptual Tasks . . . . .	34
Table 8. CSEM and NEMS Commercial Models: Conceptual Tasks . . . . .	38
Table 9. Energy Consumption Calculation Example . . . . .	45
Table 10. Array of Technology Choices and Consumer Behaviors . . . . .	75
Table 11. Floorspace Ownership and Occupancy . . . . .	77
Table 12. Consolidating Service Demand Segments . . . . .	82

## Figures

Figure 1. Commercial Sector Demand Module's Relationship to Other NEMS Modules . . . . .	12
Figure 2. Commercial Module Structure & Fundamental Process Flow . . . . .	47
Figure 3. COMM Calculation Process Flow . . . . .	51
Figure 4. COMFloorspace Calculation Process Flow . . . . .	52
Figure 5. COMServiceDemand Calculation Process Flow . . . . .	53
Figure 6. CDistGen Calculation Process Flow . . . . .	54
Figure 7. COMTechnologyChoice Calculation Process Flow . . . . .	55
Figure 8. COMConsumption Calculation Process Flow . . . . .	56
Figure 9. COMBenchmarking Calculation Process Flow . . . . .	57
Figure 10. Floorspace Survival Function Sensitivity to Average Building Lifetimes . . . . .	60
Figure 11. Alternative Gamma Assumptions and Results . . . . .	61
Figure 12. Penetration Function for Distributed Generation Submodule . . . . .	70

# 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 forecast 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 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 cogeneration 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 services.

As a component of the National Energy Modeling System integrated forecasting tool, the NEMS Commercial Module generates mid-term forecasts 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.

### ***Archival Media***

NEMS-2001 (Part of the National Energy Modeling System archive package for the *Annual Energy Outlook 2001*, DOE/EIA-0383(2001)).

### ***Model Contact***

Erin Boedecker  
Office of Integrated Analysis and Forecasting  
Demand and Integration Division  
Energy Information Administration  
United States Department of Energy, James Forrestal Building  
1000 Independence Avenue, SW  
Washington, D.C. 20585

### ***Telephone***

(202) 586-4791

## **Organization of this Report**

Section 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. Section 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. Section 3 also reviews alternative commercial sector modeling methodologies drawn from existing literature, providing a comparison to the chosen approach. Section 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 currently residing on the EIA computing platform. Appendix A lists and defines the input data used to generate parameter estimates and endogenous forecasts, 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 NEMS Buildings Sector Models,” in EIA’s *Issues in Midterm Analysis and Forecasting 1999*.<sup>1</sup>

---

<sup>1</sup>Energy Information Administration, *Issues in Midterm Analysis and Forecasting 1999*, DOE/EIA-0607(99) (Washington, DC, August 1999).

## 2. Model Purpose

### Model Objectives

The NEMS Commercial Sector Module serves three objectives. First, it develops mid-term forecasts of commercial sector energy demand, currently spanning a forecast horizon of thirty-one (31) years, from 1990 through 2020<sup>2</sup>, as a component of the NEMS integrated forecasting system. The resulting forecast is incorporated into the *Annual Energy Outlook*, published annually by the Energy Information Administration of the U.S. Department of Energy. Second, it is a policy analysis tool to assess the impacts of changes in energy markets, building and equipment technologies, environmental considerations and regulatory initiatives on commercial sector energy consumption. Third, as an integral component of the NEMS system, it provides inputs to the Electricity Market Module, Coal Market Module, Natural Gas Transmission and Distribution Module, and Petroleum Market Module 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 forecasts 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.<sup>3</sup> These forecasts are based on energy prices and macroeconomic variables from the NEMS system, combined with external data sources.

Forecasted 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 state. In addition, the NEMS supply modules referenced previously use the commercial sector outputs in conjunction with other projected sectoral

---

<sup>2</sup>The base year for the Commercial Module is currently 1995, corresponding to the last available energy consumption survey of commercial buildings. Dynamic forecasts dependent on feedback from the rest of NEMS are made for the years 1996 through 2020, whereas results reported for 1990 through 1995 are historical.

<sup>3</sup>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.

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 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

## **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 years of availability for purchase, market shares of equipment existing in 1995, installed capital costs per unit of service demand, operating and maintenance costs per unit of service demand, equipment efficiencies, removal/disposal cost factors, building restrictions, service provided, fuel used, expected equipment lifetimes, and cost trend parameters. 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 for 1995  
Median construction year of existing commercial buildings by type, vintage, and location  
Building survival parameters  
Commercial building floorspace growth

*Inputs to Service Demand Component*

Energy Use Intensities (EUI) for 1995  
Commercial technology characterizations  
    market shares of equipment existing in 1995  
    equipment efficiencies  
    building restrictions  
    service provided  
    fuel used  
Building shell efficiency indices for new floorspace  
Building shell efficiency improvement over the forecast for existing and new floorspace  
Market penetration forecasts for office equipment and "other" end-use category  
Steam EUIs to provide District Services in 1995  
Efficiencies of boilers providing District Services in 1995  
Fuel shares of District Service steam production in 1995  
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/Cogeneration Component*

Distributed generation and cogeneration technology characteristics  
    fuel used  
    years of availability for purchase  
    generation capacity  
    capital costs per kilowatt of capacity  
    installation costs per kilowatt of capacity  
    operating and maintenance costs per kilowatt of capacity  
    available federal tax credits  
    generation and thermal heat recovery efficiencies  
    annual operating hours

- penetration function parameters
- learning function parameters
- Financing parameters
- Program-driven market penetration forecast for distributed generation technologies
- Historical cogeneration of electricity data

*Inputs to Technology Choice Component*

- Consumer behavior rules
- 10-year Treasury bond rate
- Consumer time preference premium segments
- Price elasticity of hurdle (implicit discount) rates
- Minor service efficiency improvement projections
- Building end-use service capacity utilization factors
- DSM program options
- Commercial Technology characterizations
  - years of availability for purchase
  - market shares of equipment existing in 1995
  - installed capital costs per unit of service demand
  - operating and maintenance costs per unit of service demand
  - equipment efficiencies
  - removal/disposal cost factors
  - building restrictions
  - service provided
  - fuel used
  - expected equipment lifetimes
  - cost trend parameters
- Expected fuel prices

*Inputs to End-Use Fuel Consumption Component*

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

## ***Outputs***

The primary output of the Commercial Sector Demand Module is a forecast of commercial sector energy consumption by fuel type, end-use, building type, Census division, and year. The module also provides forecasts of the following for each of the forecast years:

- 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 cogeneration of electricity
- quantities of fuel consumed for distributed generation and cogeneration
- consumption of fuels to provide District Services
- nonbuilding 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 Electricity Market Module 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, below, together with the notation generally used to represent the dimensions in this report:

**Table 1. 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 ( $\geq 50,000$ ft <sup>2</sup> )	Refrigeration		Motor Gasoline	
8	Mountain	Office - Small (<50,000 ft <sup>2</sup> )	Office Equipment - PCs	Minor	Kerosene	Renewables
9	Pacific	Mercantile & Service	Office Equipment - Other than PCs		Wood	
10		Warehouse	Other		Municipal Solid Waste (MSW)	
11	U.S. Total	Other			Hydro	Other
12					Waste Heat	
13					Other Gaseous Fuels (OGF)	
14					Nuclear	

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. Of course, time is a dimension

spanned by most Commercial Module variables, and is generally represented by the subscript  $y$ , which is indexed so that a value of 1 corresponds to the year 1990 and a value of 31 corresponds to 2020.

Consumer 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 time preference premiums to characterize the commercial consumer decision-making population. These seven discount premiums, and the proportion of consumers attributed to each, vary both regionally and with end-use. The risk-free interest rate and the 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.

Distributed generation and cogeneration technologies defined in the Distributed Generation input file are represented through the use of a subscript  $ntek$ . The current Distributed Generation and Cogeneration Submodule allows for 10 types of distributed resource technologies for potential penetration in the commercial module.

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 a representative piece of 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 energy factor 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. Vintage 2) represents an updated model in this example.

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 forecast using equipment efficiency and market penetration trends. Forecasted energy demand for the Major fuels listed above takes into account the price elasticity of service demand and takeback effects as described in Chapter 4 below. Minor fuel demands explicitly incorporate price elasticity of demand impacts, in addition to being correlated with fuel prices and amount of floorspace.

## **Relationship of the Commercial Module to Other NEMS Modules**

The Commercial Module receives input data from the Macroeconomic Activity Module and the energy supply modules. The commercial floorspace forecast 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 Electricity Market Module (EMM), the natural gas prices from the Natural Gas Transmission and Distribution Module (NGTDM), and the petroleum prices from the Petroleum Market Module (PMM) are primary drivers for the technology cost comparison, the forecast of commercial sector distributed generation, and price foresight scenarios. The Commercial Module provides energy consumption forecasts by Census division and fuel to the supply modules listed above, from which supply resources and capacity plans are developed.

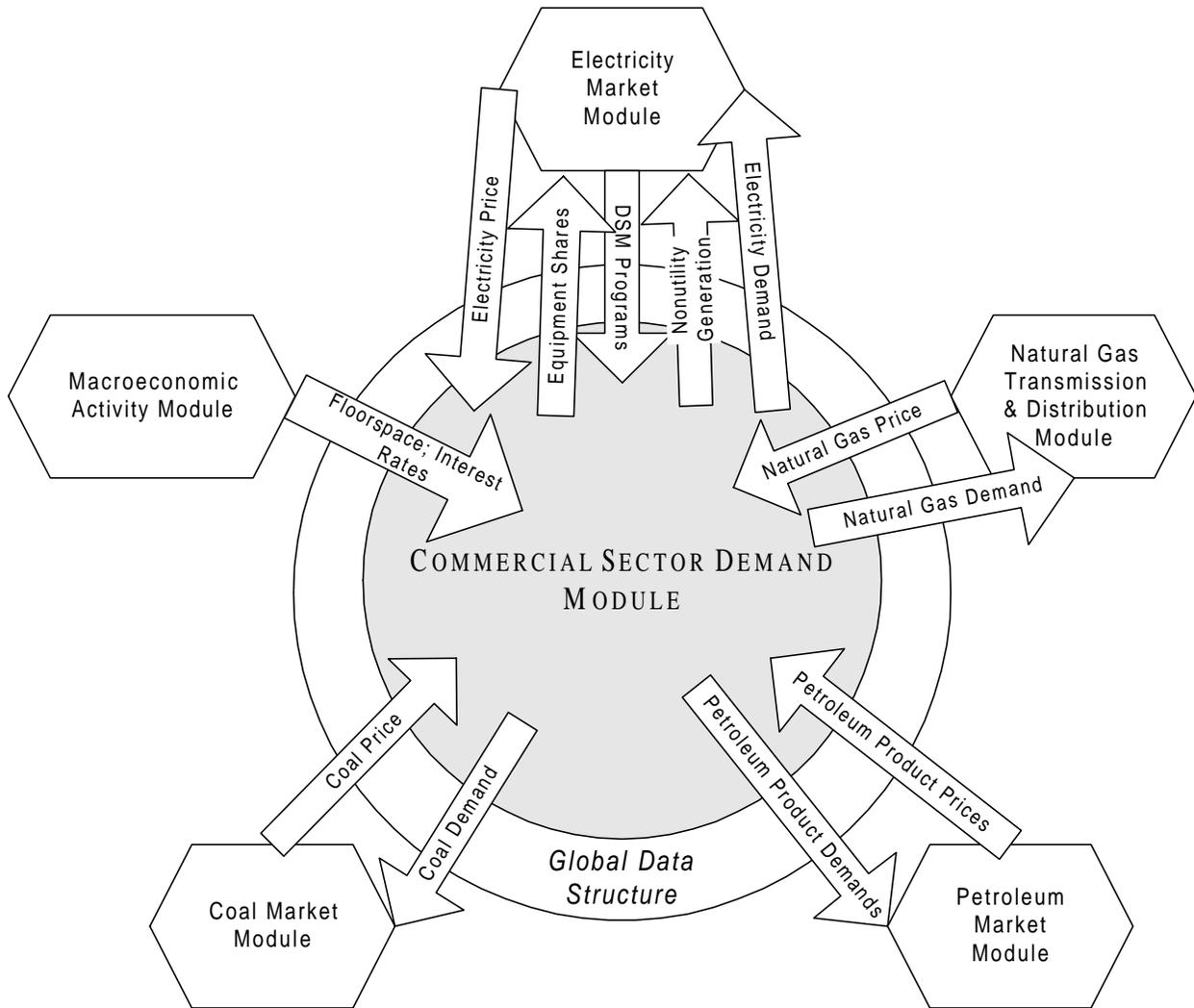
This relationship of the Commercial Module to other components of NEMS is depicted schematically in Figure 1. As shown, all exchanges of information between the modules takes place through the NEMS Global Data Structure. Not shown is the NEMS Integrating Module, which directs the activation of the sectoral 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<sup>4</sup> and the NEMS Overview<sup>5</sup>.

---

<sup>4</sup>Energy Information Administration, *NEMS Integrating Module Documentation Report 2001*, DOE/EIA-M057(2001) (Washington, DC, December 2000).

<sup>5</sup>Energy Information Administration, *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581(2000) (Washington, DC, March 2000)

**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. A simulation approach represents the characteristics of one system through the use of another system. 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, office equipment, refrigeration, and "other" energy-consuming equipment. These end-uses are modeled for eleven distinct categories of commercial buildings at the Census division level of detail.

As described previously in this report, 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 data base that forms the basis of the technology selection process is that the equipment efficiency standards described in the Energy Policy Act of 1992 (EPACT) became operative market choices in the year 1994. 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 data base by the elimination of noncompliant equipment choices and introduction of compliant equipment choices by the year the standards take effect. Through this data base, the Commercial Module is able to model equipment efficiency legislation as it continues to evolve.

There are several documented models of commercial sector energy demand. Some of these predecessor models employ simulation techniques, while others employ hybrids of econometric, engineering, and simulation

approaches. Selected commercial sector modeling initiatives, including predecessor EIA models, are discussed and compared to the selected approach further in this section.

## **Fundamental Assumptions**

### ***Floorspace Submodule***

The existing stock, geographic and building usage distribution, and vintaging of floorspace at the beginning of the dynamic portion of the model run is assumed to be the floorspace stock published as a result of the 1995 Commercial Buildings Energy Consumption Survey (CBECS)<sup>6</sup>.

New additions to the floorspace stock through the forecast 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.

### ***Service Demand Submodule***

The average equipment efficiency of the existing stock of equipment for each service is assumed to produce the CBECS 1995 energy consumption when the Energy Use Intensities (EUIs) derived from the CBECS 1995 data are applied.

The model currently assumes a simplification of the 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 forecast period (for a given service, building type and vintage, and Census division), and EUIs and average equipment efficiencies, which are the primary components of the SDI calculation, which change over the forecast, are assumed to change in such a manner as to preserve the SDI.

---

<sup>6</sup>Energy Information Administration, 1995 CBECS Micro-Data Files, February 17, 1998, see web site [www.eia.doe.gov/emeu/cbecs/](http://www.eia.doe.gov/emeu/cbecs/).

The market for the largest major services is assumed to be saturated. No increase in market penetration for the services of space conditioning, water heating, ventilation, refrigeration, and lighting is modeled. However, demand for these services grows as floorspace grows with new additions forecast 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 proportions of consumers that follow each behavioral rule are developed based upon quantitative assessment and specific assumptions that are referenced in Table A-2, Appendix A to this report.

The technology selection is performed using a discrete distribution of consumer 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 Table A-2 of 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) is forecast to increase over the forecast 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.

### **Alternative Approaches**

Building-level simulation is one approach that is applicable to the analysis of commercial sector energy demands. Additional approaches exist and have been adopted by previous modelers for such institutions as EIA, Electric Power Research Institute (EPRI), Oak Ridge National Laboratory (ORNL), and the California regulatory establishment. Selected alternative approaches are discussed below. Versions of all models discussed are those which existed in 1993; the comparison has not been updated to reflect changes made since that time in either the NEMS Commercial Sector Demand Module or the alternative approaches.

## ***Building Energy End-Use Model (BEEM): EIA***

The BEEM model, the predecessor to the NEMS Commercial Module, was designed to forecast annual commercial building energy consumption for the four Census Regions through 2010. The BEEM methodology and the NEMS Commercial Module methodology are contrasted in Table 2.

BEEM divided the commercial sector into seven building types according to primary building activity. The categories were office, food sales/service, warehouse, retail, education, continuous uses, and miscellaneous. Six energy-consuming services were modeled: space heating, space cooling, water heating, cooking, lighting, and other services. The fuels consumed to meet the service demand were electricity, natural gas, distillate fuel, and various minor fuels. The model's base year was 1986, determined from the 1986 EIA Nonresidential Building Energy Consumption Survey (NBECS-86), which provided much of the initial data for energy consumption and building characteristics.

Building energy consumption changed over time in response to commercial floorspace growth and improvements in shell integrity and equipment efficiency. The range of forecasted energy consumption depended on the variation of floorspace growth and on consumer choices among energy-using equipment. The BEEM commercial model was composed of five modules: floorspace, service demand, service capacity, technology choice, and a calibration module.

**Floorspace.** BEEM measured building stock by square footage of floorspace, for the seven building types and four Census Regions. Floorspace growth was composed of the combined effect of floorspace construction and attrition of existing stock. Base year floorspace was based on NBECS-86. This floorspace declined annually at constant attrition rates by region, while new floorspace was added each year. Total new construction for the period 1980-86 (divided by seven to obtain a yearly average, or no growth in yearly construction) was used as a proxy for the 1987 new construction pattern by building type. The 1987 estimate was then extrapolated annually by region, at the same rate of growth as regional employment growth. The module then computed total floorspace by adding existing and new floorspace by region and building type.

**Service Demand.** The service demand module tracked the energy required for each type of service (space heating, space cooling, etc.) and building type. Energy consumed for each service (in energy consumption per square foot) was multiplied by corresponding floorspace. Energy efficiency of building shells improved over time relative to 1986 stock, reducing the demand for heating and cooling services. Thus, a shell efficiency index was used as an adjustment factor to capture the reduction in service demand. Service demand was also adjusted to account for

renewable energy consumption. Renewable energy contributions were exogenously estimated for geothermal consumption, which reduced space cooling service demand, and solar and other renewables, which reduced heating service demand.

**Table 2. BEEM and NEMS Commercial Models: Conceptual Tasks**

<b>Conceptual Task</b>	<b>BEEM Methodology</b>	<b>NEMS Commercial Model Methodology</b>
Forecast floorspace additions	Increase additions (for every building type) proportionally with change in national employment; shares of building type constant throughout forecast period	Forecast by building type and Census division, based on NEMS MAM floorspace forecast
Retire floorspace	Retire constant proportion for all building type, regions, and vintages	Retire based on vintage, using convolutional decay
Measure and forecast service demand and demand penetration	Measure service demand as energy consumption in base year (indexed to consumption data)	Measure service demand in Btu of delivered energy; include short-term price sensitivity. Forecast penetration based on assumptions and market data
Retire service demand	Retire service demand by retiring equipment energy consumption	Retire service demand by retiring delivered energy, use data on age and efficiency distribution of equipment stock
Choose equipment to meet service demand	Use logit function based on cost minimization; assume initial equipment shares, fixed discount rate, and inertia factor	Use 3 behavioral assumptions, resulting in constrained optimization (cost minimization); use variation in consumer discount rate, price expectations, and inertia factor
Calculate energy consumption	Multiply service demand by equipment share-weighted inverse efficiency	Weight share of equipment chosen by inverse of average efficiency for each fuel and apply to service demand

The relative magnitude of the service demand associated with the current stock of buildings declined gradually over the forecast period and the characteristics of newer buildings became progressively more important in determining consumption levels as the older and more energy intensive buildings retired.

Service demand was adjusted for equipment efficiency, and expressed in terms of energy output requirements. The service capacity module determined how these requirements were met (capacity) and consequently how much energy was to be consumed. In the model, retiring equipment reduced existing service capacity. Replacement capacity refers to equipment that had to be purchased to replace retired equipment. Eventually, equipment reached the end of its useful lifetime and had to be replaced.

**Technology Choice.** Each year, equipment was chosen to meet new and replacement service demand. Equipment technology was chosen based on life-cycle cost criteria. The life-cycle cost for a technology was simply the capital cost plus the present value of the operating and maintenance costs for the life of the equipment (discounted at 20 percent). Ceterus paribus, the technology with the minimum life-cycle cost was chosen. The life-cycle cost was indexed to 1986. A 1986 market share corresponded to each technology option. A logit choice definition of the market share strategy was based on initial technology shares, and a price sensitivity ( $\gamma = -7$ ). Since the life-cycle costs were indexed to 1 in 1986, initial market shares were identical to the 1986 market shares. Therefore, the shares for each service added to 1. Market shares changed over time, based on the effects of fuel prices on life-cycle cost relative to 1986. Since  $\gamma$  was negative, a higher or lower fuel price respectively decreased or increased the share of the investment in new capacity that a technology received.

The impact of life-cycle technology choice on energy consumption was dampened by allowing the chosen technologies to penetrate only 20% of the market for new and replacement equipment. The remaining 80% of new/replacement demand was met by equipment that had the same efficiency as the equipment stock in the previous year.

**Benchmarking.** Equipment energy consumption was then passed through a series of calibration adjustments. The difference between State Energy Data System (SEDS) fuel consumption and forecast consumption in 1988 was the SEDS difference. In 1991, the model forecast plus the 1988 SEDS difference adjusted by a building growth rate factor was compared to the 1991 Short-Term Energy Outlook (STEO) value, yielding a STEO adjustment factor. Final consumption was computed in two steps. First, the SEDS adjustment was added to the model results. Second, this total was then adjusted by the STEO factor to produce the resulting forecast of commercial sector electricity, natural gas, and distillate fuel oil consumption.

**Minor fuel consumption.** Forecasts for residual oil, liquefied petroleum gas, coal, motor gasoline, and kerosene, were obtained by extrapolating historical consumption for each of these fuels.

**Reasons for Differences between BEEM and NEMS Modeling Approaches.** The NEMS Commercial Module floorspace forecast represents an enhancement over BEEM, as the new forecast varies by both building type and Census division over time. In addition, forecasted building type shares vary over time in the NEMS Commercial Module. In addition, the NEMS model applies a logistic decay function to calculate retiring floorspace, which is an improvement over the proportional building retirement utilized in BEEM.

The NEMS model calculates service demands and service demand market penetration based upon assumptions and market-specific data. Short-term price elasticity of demand for major fuels is considered in this calculation. This is an enhancement to the simplified indexing of service demand to energy consumption that was used by BEEM. Both models retire service demand using simplified assumptions regarding equipment retirement.

The NEMS Commercial Module Technology Choice algorithm is significantly more sophisticated than the cost-minimizing logit function approach contained in BEEM. The NEMS model applies a more comprehensive approach to equipment selection, incorporating nonmonetary considerations such as natural gas availability and consumer preferences in the behavioral rule structure of the algorithm. In addition, the NEMS model uses variable time preference premium discount rates (compared to the fixed discount rate in BEEM) and price expectations. The NEMS model incorporates detailed technology characterization information (e.g., cost and performance attributes) that correspond to explicit pieces of equipment, achieving a fine level of disaggregation in the selection process.

The NEMS model computes energy consumption based upon the equipment-specific disaggregation of technology selections, achieving a fine level of computational resolution. This methodology is an enhancement to the level of detail that was modeled in BEEM, which did not disaggregate heterogeneous equipment that met a given service.

### **Commercial End-Use Model (COMMEND): EPRI**

EPRI developed the COMMEND model to forecast commercial sector energy demands by end-use.<sup>7</sup> Within each building type and end-use segment, COMMEND forecasts fuel choice, equipment efficiency, and usage level decisions. The primary equation used in COMMEND is:

$$Sales_f = \sum_v U_{f,v} E_{f,v} S_{f,v} F_v \quad (1)$$

---

<sup>7</sup>Regional Economic Research, Commercial End-Use Data Development Handbook: COMMEND Market Profiles and Parameters, Vol.1: COMMEND Profiles and Model Structure, EPRI EM-5703, April 1988, Ch. 4.

where:

<i>Sales</i>	=	Sales of fuel f in energy units
<i>U</i>	=	Utilization (usage) rate for fuel f, building vintage v
<i>E</i>	=	End-Use Intensity in base year for fuel f, building vintage v
<i>S</i>	=	Share of building vintage v using the fuel
<i>F</i>	=	Floorspace of building vintage v

The four components of this energy equation are projected using economic relationships and parameters.

COMMEND requires the following data:

- (1) exogenous forecasts of macroeconomic indicators such as interest rates or employment, commercial sector drivers, fuel prices, floorspace inputs, weather, operating hours, etc.
- (2) market profiles - base year values for EUI, share, and floorspace.
- (3) technology data - equipment type (i.e., heat pump), capital cost, elasticities, efficiency trends, interaction parameters, etc.
- (4) economic data - decision maker data, discount rate, thermal shell parameters, demand side management data, and building and equipment energy efficiency standards.

Fuel shares and end-use intensities reflect the outcome of choices among energy technologies. Once floorspace is measured and equipment is in place, changes in usage levels reflect daily decisions about the frequency and intensity of equipment use as determined by the behavior of building managers and occupants. COMMEND uses a variety of approaches to model these decisions.

**Floorspace.** COMMEND develops vintage profiles for floorspace stock and new additions. This computation requires input data on floorspace in a distant base year, annual additions to the current base year, and a set of survival functions to link new construction to changes in the stock.

COMMEND uses a logistic survival function with a 45-year mean building lifetimes to retire floorspace built since 1940, and a geometric or exponential survival function to retire older buildings. These survival functions are used to construct time series of floorspace additions. The additions time series can also be created using a demographic approach, where a key variable such as employment or population is used to estimate additions. A mixed approach combining demographic and historical additions is used in the COMMEND model. This mixed approach involves 5 steps:

- (1) Estimate 1967 stock by working backward from 1985, using additions data and assuming an average (logistic) survival rate.
- (2) Estimate 1940 stock by working backward from 1967, using data generated by a proportional demographic variable, such as square footage per employee.
- (3) Compute average additions for each time interval (between 1940 and 1967) corresponding to each of the proportional variable's values, if the relationship to the proportional variable has changed over time.
- (4) Re-estimate average survival rate to make stock and additions series consistent with additions assumptions and proportional variable assumptions.
- (5) Repeat the first four steps using the new survival rate.

When these steps are completed, the additions and stock series are consistent with 1985 stock data, available additions data, the demographic variable, and the retirement functions.

Once the current composition of the building stock is established, it is necessary to forecast growth and change in the composition of the stock. The COMMEND model provides a general framework for forecasting floor stock growth. Users of COMMEND may use a flow approach, forecasting building additions directly and arriving at total floorspace by retiring existing stock. However, the COMMEND user's guide advises that this approach is difficult to implement, and the forecasts tend to be ill-behaved.

As an alternative approach, stock can be forecasted directly. Using this approach, stock and additions are determined by a simultaneous equation model. Floorspace stock in the forecast year is a function of exogenous variables including stock in the previous year. Additional exogenous variables may include commercial output, floorspace prices, prices of other commercial inputs such as labor, equipment, and energy. Regional income, population, and employment are often used as a proxy for commercial output. Additions in the forecast year are a function of the current stock less stock surviving from previous years.

EPRI recommends that users opt for a single variable proportional model. Employment is commonly used as the explanatory variable. This approach assumes that labor and floorspace are complementary inputs. Both increase proportionally if the commercial sector has fixed-coefficient, homogenous production functions, if relative input

prices do not change over time, and if technological change is neutral. This model does not capture investment's lagged response to the business cycle.

End-Use Intensity (EUI) is expressed as energy consumption per square foot. It is based on conditional demand analysis of EIA's NBECS-86 data. Since aggregate consumption depends on average efficiency, EUIs will change as efficiency changes. In COMMEND, average equipment efficiency changes as a result of technology choice microsimulation modules (for heating, ventilation and air conditioning (HVAC) equipment choices), or elasticity parameters (for water heating, cooking, refrigeration, lighting, and other). Average usage can change based on elasticity parameters (for all services), and fuel shares can change based on microsimulation results and penetration rate assumptions.

COMMEND assumes that consumers use different decision rules for heating, ventilation and air conditioning (HVAC) equipment as compared to other end-use equipment. The HVAC equipment is chosen sequentially. First an optimal system point is chosen for each technology on its technology curve (a plot of the relationship between energy efficiency and capital intensity for the technology, where it is assumed that energy and capital are substitutes). This is a function of price expectations and the individual's discount rate. A user-defined distribution of consumers' discount rates is entered which yields a distribution of optimal systems for each technology. The distribution of discount rates is used to prevent an unrealistic outcome: a single dominant technology choice. The discount rate is the only parameter for which COMMEND assumes consumers deviate from cost-minimizing behavior.

In the second step of the COMMEND decision process for HVAC equipment, the least cost points for each technology supply curve are compared between technologies. The least cost technologies are compared for consumers with the same discount rates. This generates a distribution of technology selections corresponding to the distribution of discount rates.

The decision simulation for non-HVAC equipment is less detailed. It assumes an existing stock of equipment with constant (average) end-use intensity. New equipment with a lower (marginal) end-use intensity is gradually weighted with the existing stock as overall demand increases. The efficiency of the new equipment for these equipment types is approximated by an elasticity response to fuel price changes.

**Table 3. COMMEND and NEMS Commercial Models: Conceptual Tasks**

<b>Conceptual Task</b>	<b>COMMEND Methodology</b>	<b>NEMS Commercial Model Methodology</b>
Forecast floorspace additions	Choice of: <ul style="list-style-type: none"> <li>■ Flow Approach</li> <li>■ Simultaneous Equation estimation using lagged dependent and exogenous macroeconomic variables</li> <li>■ Proportional approach to one variable, e.g., employment.</li> </ul>	Forecast by building type and Census division, based on NEMS MAM floorspace forecast.
Retire floorspace	Retire based on vintage, using logistic decay.	Retire based on vintage, using convolutional decay.
Measure and forecast service demand and demand penetration	Forecasts dependent on microsimulation (HVAC), or elasticity estimates. Penetration assumptions based on market data.	Measure service demand in Btu of delivered energy; include short-term price sensitivity. Forecast penetration based on assumptions and market data.
Retire service demand	Retire service demand by retiring equipment energy consumption.	Retire service demand by retiring delivered energy, use data on age and efficiency distribution of equipment stock.
Choose equipment to meet service demand	Uses cost minimization. HVAC modeled separately using a consumer discount rate distribution.	Use 3 behavioral assumptions, resulting in constrained optimization (cost minimization); use variation in consumer discount rate, price expectations, and inertia factor.
Calculate energy consumption	Multiply utilization rate by EUI and share of building vintage and floorspace vintage using fuel. Sum over fuels.	Weight share of equipment chosen by inverse of average efficiency for each fuel and apply to service demand.

**Reasons for Differences between COMMEND and NEMS Modeling Approaches.** The availability of commercial floorspace forecasts by building type from the NEMS Macroeconomic Activity Module eliminated the need to model future floorspace trends in the Commercial Module. The Commercial Module does adopt a flow methodology, though, using the MAM floorspace forecasts to develop annual new additions to floorspace. Both models retire commercial floorspace using a logistic decay function, backcasting current floorspace stock to original construction year stock.

Both models incorporate short-term price sensitivity into the calculation of service demands. COMMEND relies upon microsimulation of major services, similar to the level of detail modeled in NEMS. Both models also address the issue of market penetration for energy consuming services. COMMEND retires service demand by retiring energy consumption, while NEMS retires delivered energy, since delivered energy needs are a central concept to the technology selection process modeled in the NEMS model.

The technology selection processes of both models share certain features, specifically, an equipment-specific methodology and a distribution of consumer discount rates. COMMEND uses a cost minimization algorithm, while the NEMS model considers nonmonetary factors such as natural gas availability and consumer preferences for the same or similar equipment currently installed (inertia).

COMMEND develops energy consumption projections by aggregating the results of the technology selection process and applying building vintage shares and EUIs. This methodology flows directly from the structure of the calculations performed previously by COMMEND, and would not be applicable to the NEMS model, since building vintage shares are not computed. The NEMS model utilizes the market shares and average equipment efficiencies developed in the Technology Choice algorithm to weight equipment shares and apply these to service demands to arrive at consumption.

### ***Oak Ridge National Laboratory (ORNL) Commercial Demand Model***

The ORNL model develops annual forecasts of commercial sector energy consumption through the year 2000. These forecasts are based upon economic and engineering parameter estimates, including equipment utilization rates, fuel choices, and capital-to-energy substitution. Technological factors used in the model include equipment efficiency and building thermal characteristics (shell efficiencies). The ORNL model has been validated using the period of 1970 to 1975, incorporating the energy price shock that occurred during that time.

The ORNL model considers energy demand for ten building types: finance and other office-related, retail-wholesale, auto repair and garage, warehouse, educational, public administration, health care, religious, hotel-motel, miscellaneous commercial. Services demanded in the commercial sector are disaggregated into five end use categories: space heating, space cooling, water heating, lighting, and other. Refrigeration energy consumption is modeled within the space cooling service. Four fuels are modeled: electricity, natural gas, oil, and other, and individual equipment types are not explicitly modeled. Most of the data in the ORNL model is developed from Edison Electric Institute, American Gas Association, and Bureau of Mines sources (available source citations provided in Appendix C to this report).

Short-run commercial sector energy demands are modeled as a function of the utilization rate of equipment and the equipment stock, where the utilization is dependent on the price of fuel providing the service. The price of the service in turn is a function of the equipment and efficiency characteristics as well as the fuel price. This relationship is modeled as,

$$Q_{f,s} = U(P)_{f,s} \times S_{f,s} \quad (2)$$

where,

- $Q_{f,s}$  is the total consumption by fuel and service,
- $U(P)_{f,s}$  is the utilization rate for each fuel and service which is dependent on price,
- $S_{f,s}$  is the stock of equipment measured in terms of potential energy use.

The equipment stock is described as a function of the potential energy use to service each square foot of floorspace times the share of the floorspace by fuel and service. This is expressed as,

$$S_{f,s} = e_{f,s} \times a_{f,s} \times F \quad (3)$$

where,

- $e_{f,s}$  is the potential energy use to service each square foot of floorspace by fuel,
- $a_{f,s}$  is the share of floorspace for a service and fuel and,
- $F$  is total floorspace.

Total floorspace is determined by new additions and a decay function applied to existing stock to obtain surviving floorspace. The decay function used is,

$$f(t) = 1 - \frac{1}{1 + e^{(\alpha + \beta(t))}} \quad (4)$$

where,

- $f(t)$  is surviving floorspace,
- $\alpha, \beta$  are parameters, and
- $(t)$  is the age of the floorspace.

This decay function assumes an average building lifetime of 45 years.

Forecasted utilization factors are simply adjusted by the change in the price of the fuel weighted by the unit energy requirements for the time period times the fuel-specific own-price elasticity as taken from a study on price elasticities by Baughman and Joskow.<sup>8</sup> This allows the utilization rate to respond to a change in prices and a change in the efficiency change from one time period to another. The model discounts the any change in the utilization as a response to prices by any gains in efficiency from one time period to another.

Some assumptions are made in determining the floorspace share of each service. Floorspace is assumed to be 100% lit. The "other services" category is composed primarily of electromechanical devices, which are assumed to have an annual unit energy requirement of 2.5% (based on estimates from Arthur D. Little, Inc., cited in Appendix C to this report) . According to research conducted by Westinghouse, space cooling is assumed to increase by 1.5% annually for existing buildings, and new additions to commercial floorspace are assumed to have 90% space cooling saturation.

The fraction of floorspace served by each fuel for each end use is estimated in two steps as follows:

1. The adjusted fuel-choice equations from Baughman & Joskow are used initially to determine fuel shares. The following equation estimates the floorspace share for each end-use and fuel combination:

$$a_f = \frac{S_f / e_f}{\sum_{f=1}^4 (S_f / e_f)} \quad (5)$$

where,

- $a_f$  is the share of floorspace for fuel f
- $S_f$  is the fuel share (f) for the end-use
- $e_f$  is the energy use index for fuel f.

2. Additions to floorspace stock are determined as a function of the price of floorspace, the prices of other inputs and the level of commercial output. Commercial output is in turn a function of the demand for commercial products. The stock of floorspace is estimated as a function of per capita income and population. School enrollment is used instead of population data to forecast educational floorspace.

---

<sup>8</sup> Baughman, M.L. and P.L. Joskow, "Energy Consumption and Fuel Choice by Residential and Commercial Consumers in the United States," *Energy Systems and Policy*, Vol. 1, No. 4, 1976.

**Table 4. ORNL and NEMS Commercial Models: Conceptual Tasks**

<b>Conceptual Task</b>	<b>ORNL Methodology</b>	<b>NEMS Commercial Model Methodology</b>
Forecast floorspace additions	Forecasted using prices of floorspace, prices of other inputs, and the level of commercial output, where demand for commercial output is a function of income and population.	Forecast by building type and Census division, based on NEMS MAM floorspace forecast.
Retire floorspace	Retire based on vintage, using logistic decay.	Retire based on vintage, using convolutional decay.
Measure and forecast service demand and demand penetration	Assumed constant penetration rates for most services. Lighting assumed at 100% of floorspace.	Measure service demand in Btu of delivered energy; include short-term price sensitivity. Forecast penetration based on assumptions and market data.
Retire service demand	Retire service demand by retiring equipment energy consumption.	Retire service demand by retiring delivered energy, use data on age and efficiency distribution of equipment stock.
Choose equipment to meet service demand	Equipment types not chosen. Characteristics of equipment population determined by potential energy use, changes in efficiency, and prices.	Use 3 behavioral assumptions, resulting in constrained optimization (cost minimization); use variation in consumer discount rate, price expectations, and inertia factor.
Calculate energy consumption	Multiply utilization rate for each fuel and service by stock of equipment measured in terms of potential energy use.	Weight share of equipment chosen by inverse of average efficiency for each fuel and apply to service demand.

**Reasons for Differences between ORNL and NEMS Modeling Approaches.** As discussed in conjunction with the COMMEND model, the availability of detailed commercial floorspace forecasts from the NEMS Macroeconomic Activity Module eliminates the need to project building-level floorspace trends. Also similar to the discussion of the COMMEND model, both ORNL and the NEMS model retire floorspace using a logistic decay function. While the ORNL model makes simplifying assumptions regarding service penetration rates and lighting, the NEMS model enhances the service demand approach using EUI data from CBECS 1989 and penetration projections from Lawrence Berkeley Laboratory (LBL) studies (available citations provided in Appendix C to this report).

Similar to COMMEND, the ORNL model retires service demand based on retiring energy consumption, while the NEMS approach retires delivered energy, since it is delivered energy that must be met in the subsequently-executed Technology Choice algorithm.

Specific pieces of equipment are not characterized and competed in the ORNL model. As an alternative, the characteristics of the equipment stock that meets required service demand are determined based on the composite of

energy efficiency trends, fuel prices, and service demand patterns. The NEMS model incorporates a more detailed approach, considering nonmonetary factors such as commercial consumer behavior, fuel switching, and the introduction of new technologies in the marketplace.

### **Commercial Energy Demand Model Service (CEDMS): Jerry Jackson and Associates**

CEDMS has been used by utilities, power pools and state agencies since 1983 to forecast commercial energy use. The system provides commercial energy demand forecasts in addition to a microsimulator for prototypical buildings. The microsimulator models individual building energy requirements based upon user-specified input parameters. This capability enables the model user to develop micro-level parameter estimates for regional demand forecasting.

Microsimulation emulates a single agent in the commercial market. The process begins by defining characteristics about the decision-maker. These characteristics are the payback time period requirement, operating hours of the equipment, and the fuel preferences of the consumer. The agent then selects the equipment with the minimum payback period cost. The microsimulation uses DOE's ASEAM (A Simplified Energy Analysis Model) to define a prototypical building and its energy characteristics. Microsimulation is the primary determinant of saturation and efficiency choices.

The payback period cost equation is estimated using the maximum-likelihood method. The equation is,

$$\frac{\text{Payback period}}{\text{equip. cost}} = \frac{\text{Equip. Cost}}{\text{cost}} + \frac{\text{Install. cost}}{\text{cost}} + (\text{Price}_f \times \text{EUI} + \beta_{f,b}) \times \frac{\text{Payback req.}}{\text{cost}} \quad (6)$$

where the subscript *f* refers to fuel, and  $\beta$  is a random variable determined outside of the model run with mean of *b* and measure of dispersion *D*. Additional terms used in Equation (6) are further defined in this section.

Utilization changes by equipment vintage over the forecast according to the following equation,

$$U_t = U_{t-1} \times \left( 1.0 + \frac{P_{f,t} - P_{f,t-1}}{P_{f,t}} \right) \times \frac{\text{Utiliz.}}{\text{elast.}} \quad (7)$$

where the *t* subscript refers to the time dimension, and the other subscripts are as previously defined for this model.

CEDMS uses a disaggregated appliance stock approach to determine energy by service, fuel and building type. The primary equation to accomplish this is,

$$Consump_{s,f,b} = \frac{Total\ bldg.}{floorspace} \times Satur.\ rate \times EUI \quad (8)$$

where the energy use intensity (EUI) is described as,

$$EUI = EUI_{t_0} \times Efficiency\ index \times Utilization\ index \quad (9)$$

$t_0$  refers to the base year of the forecast, and Satur. rate is the appliance saturation rate.

CEDMS relies upon annual floorspace vintage information to monitor building shell and equipment efficiencies. Floorspace is retired through a logistic decay function. Appliances are replaced at average lifetimes or earlier if the new appliance payback period cost is less than the existing appliance operating cost over the same period.

The energy use equation in its final form is then,

$$Consumption_{f,s,b,v} = A \times d \times SAT \times EUI_{t_0} \times E \times U \quad (10)$$

where,

- A is new floorspace constructed,
- d is the floorspace retirement parameter based on the logistic decay function,
- SAT is the saturation rate for equipment,
- $EUI_{t_0}$  is the base year energy use intensity,
- E is the energy efficiency index,
- U is the energy using equipment utilization index.

Space heating and water heating fuel choices are determined through a building simulation subroutine within the model framework. CEDMS estimates parameters using historical data through either simulation methods or utilization elasticities.

**Table 5. CEDMS and NEMS Commercial Models: Conceptual Tasks**

<b>Conceptual Task</b>	<b>CEDMS Methodology</b>	<b>NEMS Commercial Model Methodology</b>
Forecast floorspace additions	Exogenous floorspace forecast.	Forecast by building type and Census division, based on NEMS MAM floorspace forecast.
Retire floorspace	Retire based on constant rate of historical demolition data in region.	Retire based on vintage, using convolutional decay.
Measure and forecast service demand and demand penetration	Saturation (fuel choice) relationships are determined by microsimulations or efficiency elasticities.	Measure service demand in Btu of delivered energy; include short-term price sensitivity. Forecast penetration based on assumptions and market data.
Retire service demand	Retire service demand by retiring equipment energy consumption.	Retire service demand by retiring delivered energy, use data on age and efficiency distribution of equipment stock.
Choose equipment to meet service demand	Microsimulation process estimates the payback period of the equipment to determine equipment choice.	Use 3 behavioral assumptions, resulting in constrained optimization (cost minimization); use variation in consumer discount rate, price expectations, and inertia factor.
Calculate energy consumption	Multiply total building floorspace by saturation rate and EUI.	Weight share of equipment chosen by inverse of average efficiency for each fuel and apply to service demand.

**Reasons for Differences between CEDMS and NEMS Modeling Approaches.** Both CEDMS and the NEMS model utilize exogenous forecasts of commercial floorspace. The NEMS model requires some additional processing of the DRI forecast received from the NEMS Macroeconomic Activity Module, specifically, to develop new additions to floorspace by the eleven building types required for the flow model approach discussed previously in this report. The NEMS methodology of retiring floorspace based on vintaging and a logistic decay function is more sophisticated than the simplifying assumption made by CEDMS that retirements are a constant proportion based on historical demolitions.

The CEDMS model microsimulates fuel choice relationships to determine service demands that must be met through technology selections. Equipment payback periods are then simulated, in order to determine equipment choices. The NEMS Commercial Module has as its starting point the CBECS 1989 data base of floorspace, fuel consumption, fuel shares and market shares, which effectively eliminates the need to microsimulate fuel proportions or market shares in the base year. The technology selection algorithm of the NEMS model effectively computes relative technology costs based on a distribution of discount rates, microsimulating building equipment choices. The NEMS model takes into account both monetary and nonmonetary factors in the decision process.

CEDMS relies upon the equipment saturations calculated in the service demand algorithm to develop end-use consumption. CEDMS also applies EUIs to projected commercial floorspace in this calculation. The NEMS Commercial Module does not explicitly calculate equipment saturations. Instead, the primary outputs of the NEMS Technology Choice algorithm are fuel proportions of service demand and inverse average equipment efficiencies. These outputs are applied to calculated service demands to develop end-use consumption.

### ***Commercial Building Energy Demand Forecast Model (CBEF): California Energy Commission (CEC)***

CBEF was developed to address operating and policy issues relevant to the California energy establishment. The theoretical basis and structure of CBEF is similar to the Jackson model described previously in this section.

CBEF determines end-use consumption based on total commercial floorspace, the proportion of floorspace receiving an end-use energy service and the building type, efficiency, and use of equipment. CBEF uses the Jackson-type equation to forecast consumption for all services except miscellaneous. Miscellaneous consumption is forecasted using assumed growth rates for office equipment and other miscellaneous consumption. The office equipment growth rates vary over building type and time, and other miscellaneous consumption is assumed to grow continually at two percent per year.

CBEF applies two sets of engineering simulation results to incorporate internal load adjustments for office equipment in the space heating and space cooling services. The simulations are for prototypical buildings in Fresno and San Francisco to account for differing climate regions.

The seven major utility planning areas of California are modeled. These appear in Table 6 below. CBEF forecasts energy consumption for eleven building types, ten end-uses, and three fuels, also listed in Table 6.

**Price Responsiveness.** The utilization rate, which is specified by fuel, end-use, building type and vintage, is a function of equipment efficiency, fuel price, and utilization short-run price elasticities. CBEF forecasts a short-run response to price changes in the utilization rate of energy consuming equipment. In addition, a price increase will induce the installation of higher efficiency units for new floorspace and for replacement of retiring equipment. CBEF does not explicitly address retrofits.

**Table 6. CBEF Variable Classification**

Building Types	Planning Areas	Fuels	End-uses
Office-small Office-large Restaurants Retail Stores Food/Liquor Stores Warehouses Schools Colleges/Trade Health Care Hotel/Motel Miscellaneous	Pacific Gas & Electric L.A. Dept. of Water & Power Sacramento Municipal Utility District San Diego Gas & Electric Southern California Edison Burbank, Glendale, Pasadena Other	Electricity Natural Gas Other	Space Heat Space Cooling Ventilation Water Heating Cooking Refrigeration Lighting -Indoor Lighting - Outdoor Office Equipment Miscellaneous

**Equipment.** CBEF improves upon its predecessor models by using an end-use equipment vintaging algorithm. The CBEF Model applies a Weibull distribution function to compute the surviving share of an equipment vintage in any given year. The function is expressed as,

$$g_t = e^{-(t/L)^b} \tag{11}$$

where,

- $g_t$  is the survival fraction,
- $t$  is the age of the equipment, and
- $L, b$  are parameters determining the shape of the function.

This function is used to decay all equipment after the 1964 base year. The 1964 stock is composed of all previous surviving vintages. Therefore the composition of the 1964 stock is determined assuming that the stock of appliances is in equilibrium and normally distributed. By applying the same type of decay function, the 1964 stock is the sum of all surviving stock from previous years.<sup>9</sup>

---

<sup>9</sup> This vintaging algorithm is a potential enhancement to the NEMS model that is currently under consideration.

**Floorspace.** Commercial floorspace forecasts are generated by a mixed use of stock demand and constant stock ratio approaches. The resultant stock adjustment model is described by the log-log equation,

$$\ln\left(\frac{Y_t}{X_t}\right) = b_0 + b_1 * \ln\left(\frac{PF_t}{PO_t}\right) + b_2 * \ln(M_t) + b_3 * \ln(PCI_t) + b_4 * \ln\left(\frac{Y_{t-1}}{X_{t-1}}\right) \quad (12)$$

where,

- $Y_t/X_t$  is floorspace stocks over by a commercial output proxy (e.g. employment, taxable sales, etc.),.
- $PF_t/PO_t$  is the price of floorspace, as measured by the construction materials price index over the average hourly earnings per worker by sector,
- $M_t$  is the money supply,
- $PCI_t$  is per capita income,
- $Y_{t-1}/X_{t-1}$  is the dependent variable lagged one period, and
- $b_i$  for  $i = 0, \dots, 4$  are regression coefficients.

The equation is estimated using OLS for ten building types and seven regions. Floorspace stock data is included from various state agency sources connected with the regulation of specific sectors. These agencies include the California State Health Planning and Development and the California State Department of Education. New additions to commercial floorspace are developed based on F.W. Dodge data.

The share of any particular vintage of building stock survives according to the following logistic decay function which is taken from the Jackson Model,

$$\text{Surviving Share of building vintage}_t = \frac{1}{1 + e^{6.91 - 0.126 \cdot t}} \quad (13)$$

This function assumes a mean building lifetime of 55 years whereas the Jackson Model uses a 45 year average building lifetime. This implies that the increase of new and more efficient building shell technology and equipment is more gradual than the Jackson Model.

**Energy Use Intensity.** Prototype buildings are developed for two climate regions: Northern and Southern California. Within each climate region prototypes are simulated for each building type.

**Fuel Saturations.** Three vintages are used in determining fuel saturations. The vintages are pre-1965, 1966-1974, and post-1975. Estimations are made for each vintage for both space heating and cooling.

**Price Elasticities.** The CBEF utilizes a Nguyen and Chen algorithm to estimate price elasticity of demand. The model explains a range of variations in demand per square foot. The following explanatory variables are included in the model:

- output of commercial services,
- fuel prices, specifically electricity and natural gas prices,
- heating degree days, and
- cooling degree days.

**Table 7. CBEF and NEMS Commercial Models: Conceptual Tasks**

<b>Conceptual Task</b>	<b>CBEF Methodology</b>	<b>NEMS Commercial Model Methodology</b>
Forecast floorspace additions	Floorspace forecasted using a mixture of stock demand and constant stock ratio approaches.	Forecast by building type and Census division, based on NEMS MAM floorspace forecast.
Retire floorspace	Retire based on vintage, using logistic decay .	Retire based on vintage, using convolutional decay.
Measure and forecast service demand and demand penetration	EUIs are developed using prototypical buildings in two climate regions.	Measure service demand in Btu of delivered energy; include short-term price sensitivity. Forecast penetration based on assumptions and market data .
Retire service demand	Retire service demand by retiring equipment energy consumption using equipment decay rates.	Retire service demand by retiring delivered energy, use data on age and efficiency distribution of equipment stock.
Choose equipment to meet service demand	Equipment efficiency and utilization rate are forecasted. Individual equipment technologies are not modeled.	Use 3 behavioral assumptions, resulting in constrained optimization (cost minimization); use variation in consumer discount rate, price expectations, and inertia factor.
Calculate energy consumption	Multiply utilization rate by EUI and floorspace.	Weight share of equipment chosen by inverse of average efficiency for each fuel and apply to service demand.

**Reasons for Differences between CBEF and NEMS Modeling Approaches.** Both CBEF and NEMS utilize building stock vintaging information to develop forecasted floorspace, but the NEMS model uses a flow methodology to project new additions to floorspace while CBEF uses a constant stock ratio algorithm. The NEMS

approach is potentially more dynamic in nature than the CBEF method. Floorspace is retired in both models through a logistic decay function.

Both CBEF and NEMS utilize EUIs based on specific building parameters, CBEF's developed from microsimulation of prototypical buildings and NEMS' based on CBECS 1989 survey data. CBEF employs an equipment decay rate algorithm to compute retiring service demand, while NEMS currently assumes proportional service demand retirement. The CBEF methodology is a potential enhancement to the NEMS treatment of retiring service demand.

CBEF does not explicitly model individual technologies. Instead, composite equipment efficiencies and utilization factors are forecasted. Projected utilization rates are then multiplied by EUIs to obtain consumption forecasts. In contrast, the NEMS model characterizes specific equipment and selects this equipment based upon behavioral assumptions for each decision type. The resulting equipment market shares and the equipment efficiencies that correspond to each market share are then used in conjunction with calculated service demands to project end-use consumption. The NEMS approach results from the treatment of service demand at the Census division, building, and service level of detail. This approach complements the detailed treatment of technology selection, enabling the results of the service demand calculation to be used to compute end-use consumption.

### ***Commercial Sector Energy Model (CSEM): Energy Information Administration***

CSEM is a product of EIA's Office of Energy Markets that was a component of the PC-AEO (spreadsheet) model. The PC-AEO system was used to produce the *Annual Energy Outlook* prior to the development of BEEM. CSEM generates annual commercial sector demand forecasts through the year 2000. Forecasts are developed for the major fuels of electricity, natural gas, and distillate fuel along with minor fuels (e.g., residual fuel oil). CSEM models the commercial sector at the four Census Region level of detail.

CSEM projects commercial floorspace using the 1983 NBECS. 1983 new additions to floorspace are estimated as one-tenth of NBECS floorspace constructed between 1974 and 1983. The base year of the forecast is then set to 1983. Base year floorspace is multiplied by regional population growth rates and lagged GNP to obtain floorspace additions. Annual surviving floorspace is determined using a constant survival rate applied to existing vintages.

Energy use intensities are developed for new and surviving floorspace. Capital stock energy use is calculated using new and surviving floorspace as weights. Fuel price effects are assumed to be zero.

Price-impacted energy intensity is then computed as,

$$q = \exp(e \times \ln(p/p_{83})) \times q' \quad (14)$$

where,

- q is the price impacted energy intensity,
- p is the fuel price,
- p<sub>83</sub> is the fuel price in the base year,
- q' is the capital stock energy intensity independent of price, identical to the weighted sum of 1983 NBECS energy consumption rates in new and surviving floorspace using a relative price index with a 1983 base year.

Total energy forecasts are generated by multiplying the price-affected energy intensity estimates by the total floorspace forecast.

**Reasons for Differences between CSEM and NEMS Modeling Approaches.** As discussed in the comparison of COMMEND and NEMS, the availability of exogenous projections of commercial floorspace in NEMS eliminates the need to explicitly forecast building-level annual new additions. Instead, NEMS apportions new additions into the eleven CBECS 1989 building types. CSEM utilizes NBECS 1983 floorspace stock and macroeconomic driver variables to forecast commercial floorspace, using an approach that is conducive to developing a simulation based on the survey data. CSEM retires existing floorspace based on a constant survival rate, which does not consider floorspace vintaging and building lifetimes. The NEMS Commercial Module backcasts the base year floorspace stock to the original years of construction and applies a logistic decay function to model more accurately the shape of the building retirement function.

Both CSEM and the NEMS Commercial Module employ price impacts in the service demand calculation. CSEM computes price-affected EUIs to account for fuel price impacts and energy consumption patterns in newer buildings. NEMS explicitly includes short-run price elasticity of demand estimates for the major fuels of electricity, natural gas, and distillate. The NEMS approach uses finely disaggregated EUIs based on CBECS 1989, which were not available when CSEM was developed. Retiring service demand is not treated in CSEM. In contrast, the NEMS Commercial Module retires a portion of delivered energy each forecast year that corresponds to retiring commercial floorspace.

As discussed previously in this section, the NEMS Commercial Module technology selection procedure incorporates numerous cost-based and nonmonetary decision factors in the determination of equipment market

shares and the resulting inverse average equipment efficiency. The results of this selection process and the aggregating calculations are directly input to the calculation of end-use consumption. The CSEM approach directly uses the price-affected EUIs to the floorspace forecast to obtain consumption values, not considering explicit equipment choices. The NEMS approach provides a finer level of resolution in selecting individual technologies and calculating consumption based on the specific equipment mix.

**Table 8. CSEM and NEMS Commercial Models: Conceptual Tasks**

<b>Conceptual Task</b>	<b>CSEM Methodology</b>	<b>NEMS Commercial Model Methodology</b>
Forecast floorspace additions	Forecast based on NBECS 1983 stock data and multiplying by lagged GNP and population growth rates.	Forecast by building type and Census division, based on NEMS MAM floorspace forecast.
Retire floorspace	Retire based on a constant survival rate of existing floorspace.	Retire based on vintage, using convolutional decay.
Measure and forecast service demand and demand penetration	EUIs assume to higher for electricity and gas in newer buildings. Price affected intensity computed using fuel prices and weighted sum of NBECS consumption rates in new and surviving floorspace.	Measure service demand in Btu of delivered energy; include short-term price sensitivity. Forecast penetration based on assumptions and market data.
Retire service demand	none	Retire service demand by retiring delivered energy; use age and efficiency distribution of equipment stock data.
Choose equipment to meet service demand	none	Use 3 behavioral assumptions, resulting in constrained optimization (cost minimization); use variation in consumer discount rate, price expectations, and inertia factor.
Calculate energy consumption	Multiply price affected energy intensity by total floorspace forecast.	Weight share of equipment chosen by inverse of average efficiency for each fuel and apply to service demand.

## **Summary of Reasons for Selecting NEMS Commercial Model Approach over Alternative Approaches Adopted in Previous Commercial Models**

### ***BEEM***

The BEEM floorspace forecast did not address variation of floorspace by Census division and building type over time. The NEMS approach incorporates this consideration. The BEEM service demand algorithm was a simple indexing of service demand to energy consumption. The NEMS approach is much more sophisticated, treating such considerations as district services, service demand price elasticity, and office equipment market penetration. The BEEM technology choice algorithm was a simplified logit function that minimized life-cycle costs. The NEMS Technology Choice algorithm is much more sophisticated and flexible, and considers a myriad of issues such as equipment availability, energy efficiency standards, technology competition, retrofit decisions, and technological breakthroughs that introduce new classes of equipment to the marketplace.

### ***COMMEND***

COMMEND models only two regions, and NEMS models nine Census divisions, incorporating extensive Census division level data. COMMEND utilizes a cost-minimization algorithm to compute technology selections. NEMS applies a highly sophisticated Technology Choice algorithm that considers numerous facets of the consumer choice process as described previously. COMMEND applies building vintage shares and EUI information to the technology selection results to develop end-use consumption. The NEMS Technology Choice algorithm incorporates a finer level of detail that allows for numerous types of aggregations to be performed to calculate end-use consumption at several desired levels of aggregation.

### ***ORNL***

ORNL makes simplifying assumptions regarding service penetration rates and lighting. NEMS enhances the service demand approach by employing detailed EUI data developed from CBECS 1989, along with office equipment market penetration studies performed by Lawrence Berkeley Laboratory. In addition, NEMS treats lighting as a major service and models bulb competition in the Technology Choice algorithm. ORNL does not characterize and compete specific classes of equipment, relying instead upon characterizations developed from energy efficiency trends, fuel prices and service demand patterns. The NEMS approach competes specific technology classes to enable a finer level of disaggregation of the choice calculation that is central to the model.

## ***CEDMS***

CEDEMS employs the simplifying assumption that floorspace retirements are a constant proportion based on historical demolitions. NEMS applies a convolution algorithm that reconstructs floorspace back to the original construction vintage, and evolves existing and new floorspace stock throughout the forecast period.

## ***CBEF***

CBEF is a regional model based upon seven distinct areas of the state of California. NEMS models nine Census divisions. NEMS employs a more dynamic modeling structure for the convolution of commercial floorspace over the forecast period. CBEF does not explicitly model individual technology classes, relying instead upon composite efficiencies and utilization rates across classes of technologies. NEMS models distinct technology classes, enabling a finer tracking of equipment selections and resultant average equipment efficiencies.

## ***CSEM***

CSEM retires existing floorspace based on a constant survival rate, while NEMS incorporates variation through the convolutional approach to floorspace retirement. The EUI estimates employed in the CSEM model are not as finely disaggregated as the EUIs used in NEMS, enabling a greater level of disaggregation in NEMS. CSEM does not treat retiring service demand, and NEMS does. CSEM does not incorporate a technology choice procedure, and instead directly uses price-adjusted EUIs and forecasted floorspace to compute end-use consumption. This approach does not consider a plethora of factors that impact final consumption, such as those considered in the NEMS Technology Choice Submodule.

## 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.<sup>10</sup> 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 five basic steps for each forecast year. The first step is to forecast commercial sector floorspace. The second step is to forecast the energy services (e.g., space heating, lighting, etc.) required by that building space. The third step is to forecast electricity generation and energy services to be met by distributed generation technologies. The fourth step is to select specific technologies (e.g., gas furnaces, fluorescent lights, etc.) to meet the demand for energy services. The last step is to determine how much energy will be consumed by the equipment chosen to meet the demand for energy services. New construction, surviving floorspace, and equipment choices forecast 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 overview, flow diagrams are provided and the calculations performed by each of the forecasting components are described in detail.

### ***Commercial Building Floorspace Forecast***

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

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

---

<sup>10</sup>There is a small amount of commercial energy consumption (from uses such as street lights), that is not attributed to buildings. This is discussed in the End-Use Consumption section.

## Service Demand Forecast

Once the building inventory is projected, the model develops a forecast of demand for energy-consuming services within buildings. Consumers do not demand energy per se, but the services that energy provides.<sup>11</sup> 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
- Space Cooling
- Ventilation
- Water Heating
- Lighting
- Cooking
- Refrigeration
- Office Equipment - Personal Computers
- 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 forecast 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 equipment that is chosen to replace this 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 level of usage of a service in response to a change in energy prices. The model accounts for this behavioral impact by adjusting service demand forecasts using price elasticity of demand estimates for the major fuels of electricity, natural gas, and distillate fuel.<sup>12</sup> 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

---

<sup>11</sup>Lighting is a good example of this concept. It is measured in units which reflect consumers' perception of the level of service received: lumens.

<sup>12</sup>The calculation described is actually performed on the fuel consumption forecast 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.

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" modification of pure price elasticity.

### ***Decision to Generate or Purchase Electricity***

The Distributed Generation and Cogeneration submodule projects electricity generation, fuel consumption, and water and space heating supplied by distributed generation technologies. Historical data are used to derive electricity cogeneration for 1996. In addition, program-driven installations of solar photovoltaic systems and fuel cells are input based on information from DOE and DOD, referenced in Appendix A. After 1996, a forecast of distributed generation and cogeneration of electricity is developed based on the economic returns projected for distributed generation and cogeneration technologies. The module uses a detailed cash-flow approach to estimate the number of years required to achieve a cumulative positive cash flow. Penetration of these technologies is a function of how quickly an investment in a technology recoups its flow of costs.

### ***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 year of the forecast),
- *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).

Thus, consumers must choose equipment to meet service demand under three conditions, as mentioned above. Each condition 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.<sup>13</sup> Using a similar methodology, 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.

These behavior rules are designed to represent empirically the range of economic factors which 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 proportions 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.<sup>14</sup>

The model is designed to choose among a discrete set of technologies exogenously characterized by commercial availability, capital costs, operating and maintenance (O&M) costs, removal/disposal costs, efficiencies, and lifetime. 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. Starting with AEO2000, 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 technologies faster diffusion into the marketplace if fuel prices increase markedly for a sustained period of time.

---

<sup>13</sup>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.

<sup>14</sup>Additional detail regarding the derivation of the choice proportions is provided in Appendix A to this report.

## Energy Consumption

Following the choice of equipment to satisfy service demands, 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 9. 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 9, Column 3); divide service demand (3) by the average efficiency (4) to derive fuel consumption by fuel type.

**Table 9. Energy Consumption Calculation Example**

Fuel (1)	Service Demand (100 MMBtu out)		Average efficiency (Btu out/Btu consumed) (4)	Fuel Consumption (MMBtu) (5) = (3)/(4)
	Proportion of Service Demand (2)	Amount of Service Delivered (MMBtu out) (3)=(2)*100		
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

Forecasted 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 nonbuilding commercial sector energy consumption (e.g., radio transformer towers) and provides a consistent starting point for the forecast. The benchmarking procedure is further discussed in the last section of the main text of this report.

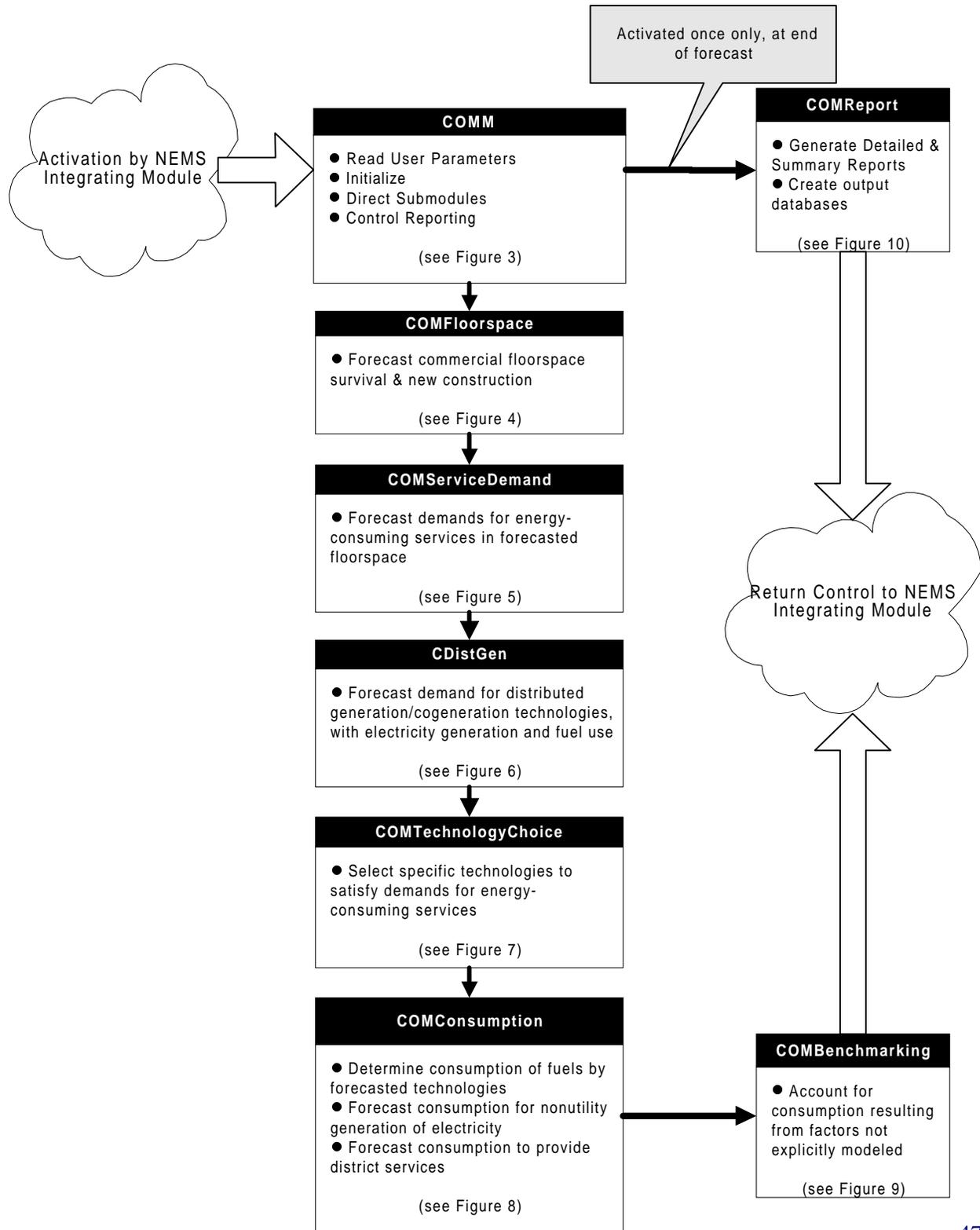
## Flow Diagrams

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 forecast of fuel demands consists of six steps:

1. A forecast 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 cogeneration technologies are chosen to meet electricity demand in place of purchased electricity where determined to be 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 services are accounted for (COMConsumption Submodule).
6. Results by fuel and Census division are adjusted to match the 1990 through 1997 State Energy Data System (SEDS) historical data, and optionally the 1998-2001 forecasts of the *Short Term Energy Outlook* (STEO) (COMBenchmarking Submodule).

**Figure 2. Commercial Module Structure & Fundamental Process Flow**



The Commercial Module is activated one or more times during each year of the forecast 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 determines whether a dynamic forecast for the current year is warranted, retrieves user-specified options and parameters, performs certain initializations, and directs the processing flow through the remaining submodules. It also detects the occurrence of the conclusion of the forecast 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 NEMS Macroeconomic Activity Module (MAM) total commercial floorspace forecast by Census division, building type, and year. In addition, base year building stock characteristics and building survival parameters developed based on analysis of CBECS 1995 and additional sources (further referenced in Table A-2 of 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 (1995) Energy Use Intensities (EUIs), office equipment market penetration forecasts, base year equipment market shares and stock efficiencies, equipment survival assumptions, building shell efficiencies, weather data, and district service information. The Service Demand Submodule forecasts 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 Cogeneration Component of the model, CDistGen. Technology specific inputs and financing parameters are required by the Distributed Generation and Cogeneration Submodule, along with additional inputs such as historical commercial cogeneration data, program-driven market penetration forecasts, and fuel prices. The Distributed Generation and Cogeneration 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 time preference segmentation information specific to the Commercial Module, and NEMS system outputs including Treasury Bill rates from the Macroeconomic Activity Module (MAM) and fuel prices from the Electricity Market Module, Natural Gas Transmission and Distribution Module, and Petroleum Market Module, are required by the Technology Choice Submodule. The result of processing by this submodule is a forecast 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 service demand forecast generated by the Service Demand Component to produce the forecast of major fuel consumption by building type, Census division, and end-use. Several additional considerations are incorporated into the final forecast, including accounting for the fuel used for electricity generation and cogeneration in commercial buildings and fuel consumption for the purposes of providing District Services. Demands for the five minor fuels are also forecast by this component using the floorspace forecast together with fuel prices and input regression parameters.

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

A final reporting subroutine, COMReport, generates detailed documentation on the Final Control and Reporting Loop of the last forecast year. Numerous subcategories and additional considerations are handled by the model for

each of the broad process categories given above. These are described below under the headings of the applicable subroutines, and explicitly stated in mathematical form in Appendix B.

**Figure 3. COMM Calculation Process Flow**

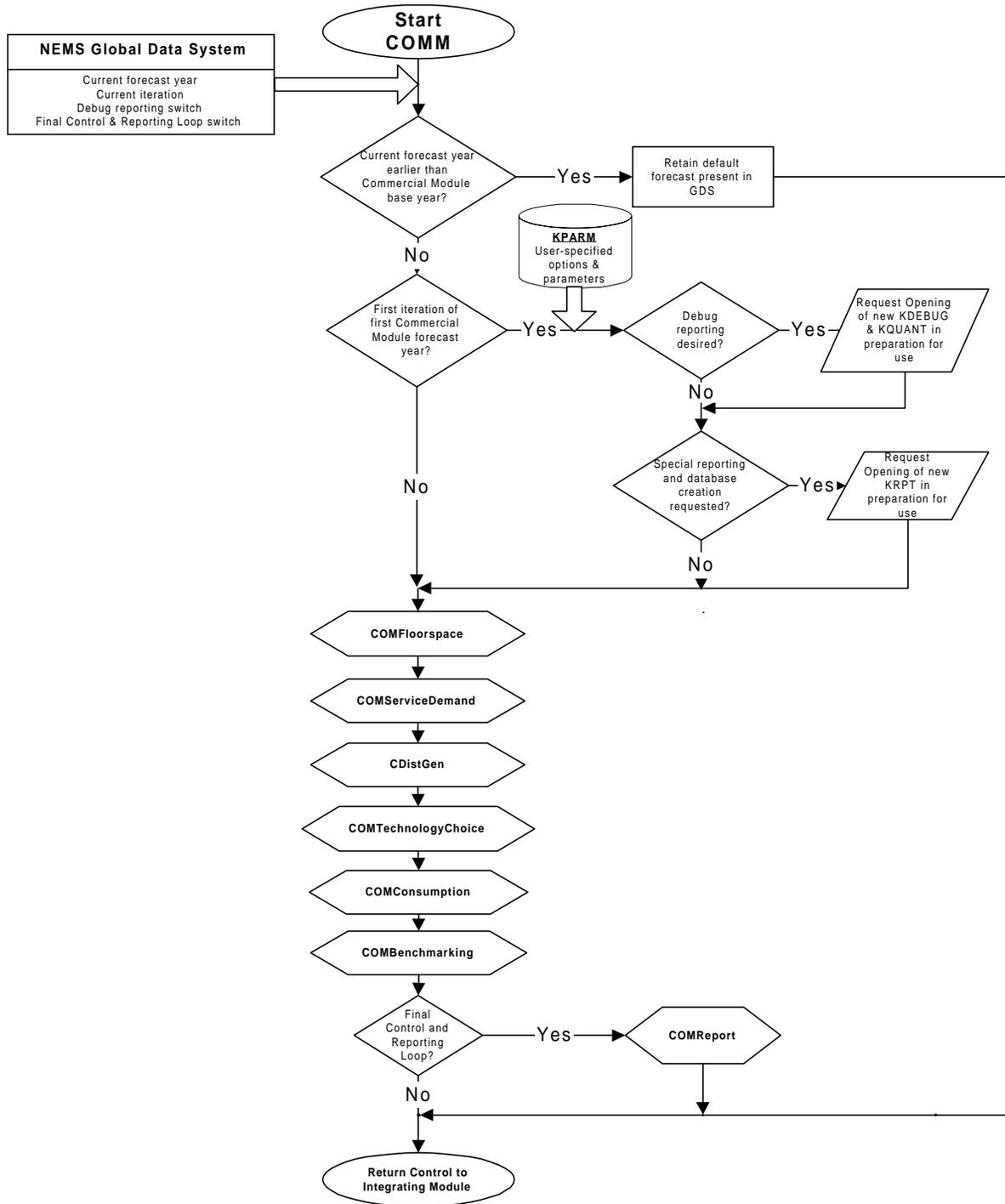


Figure 4. COMFloorspace Calculation Process Flow

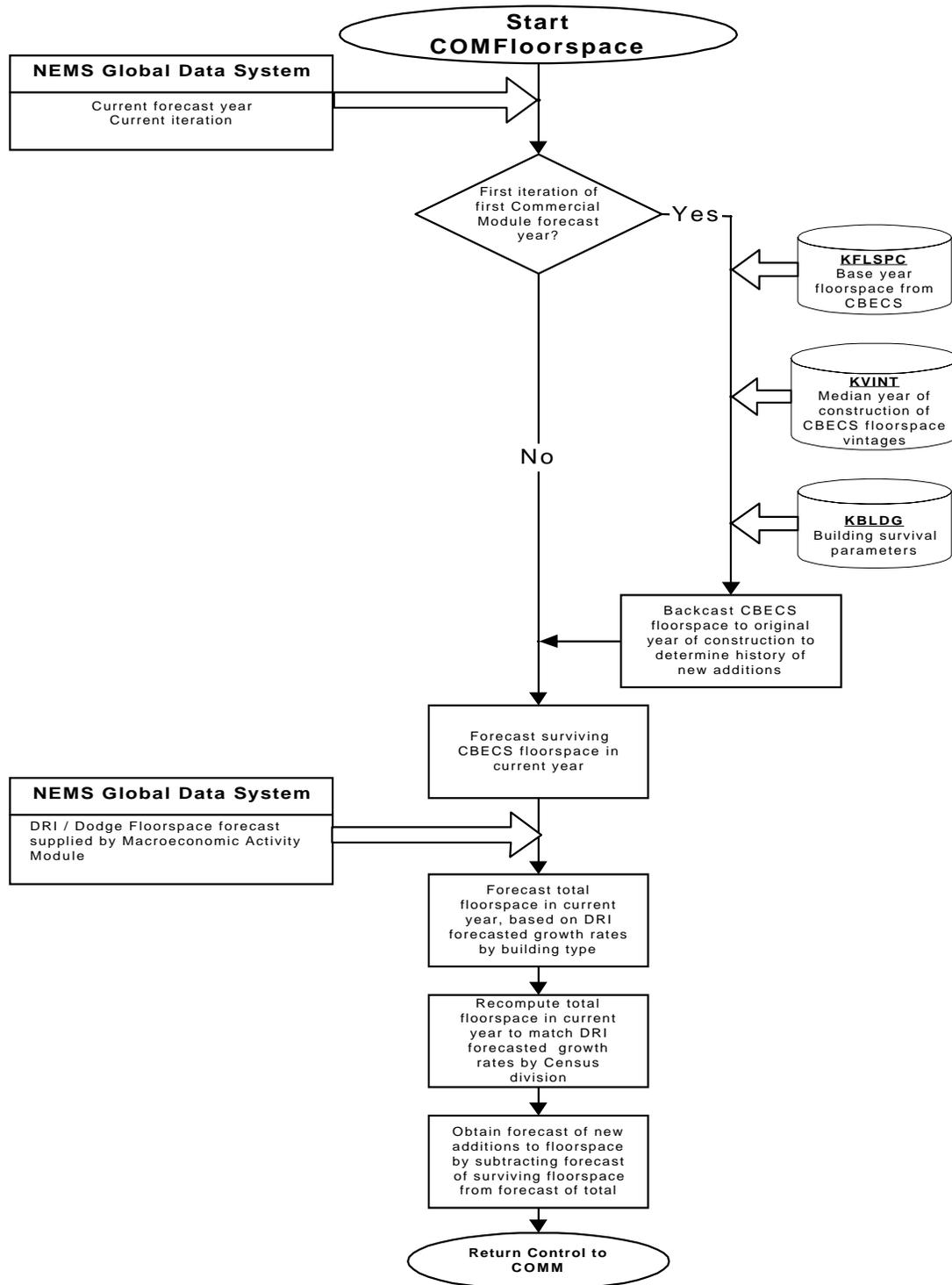


Figure 5. COMServiceDemand Calculation Process Flow

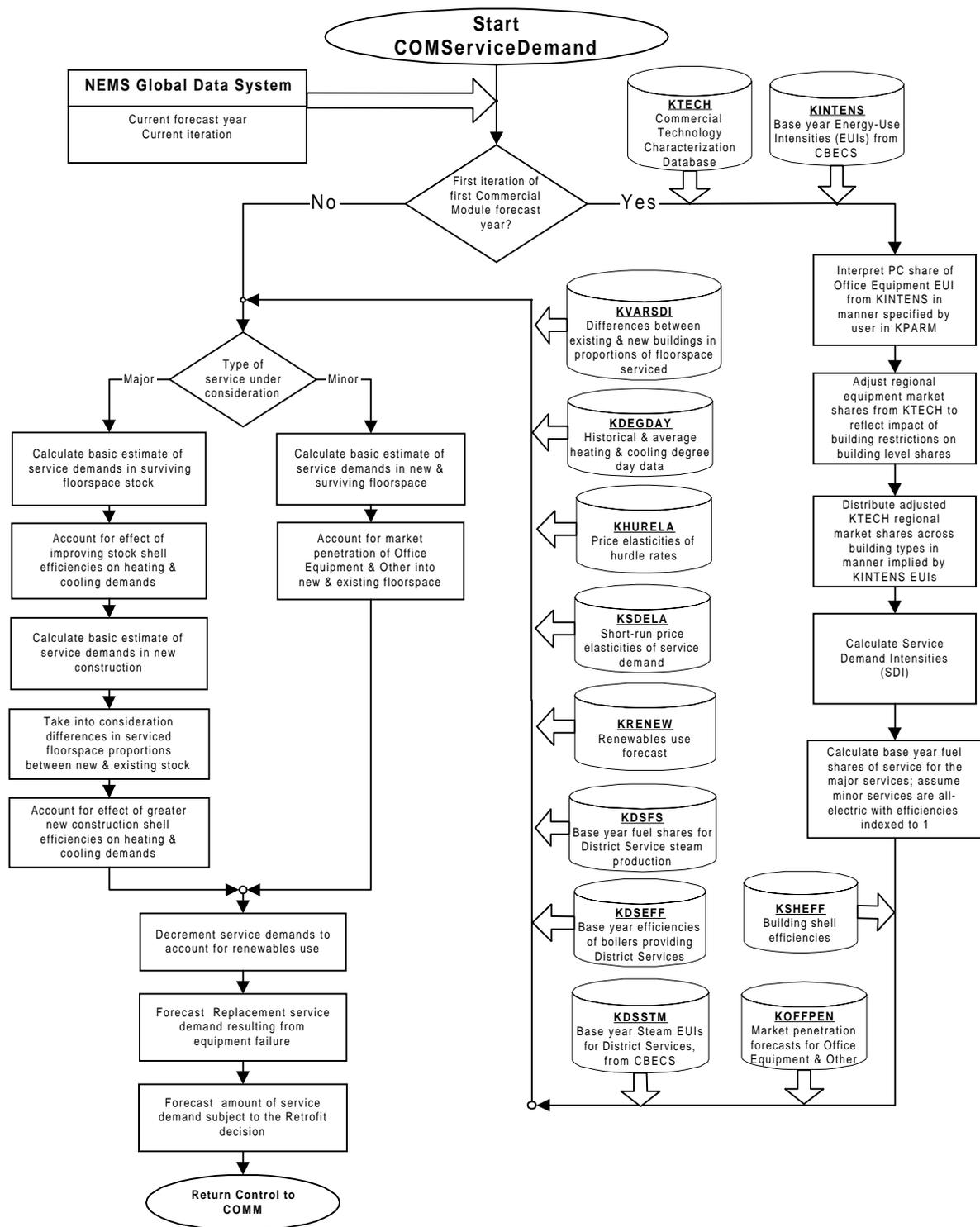


Figure 6. CDistGen Calculation Process Flow

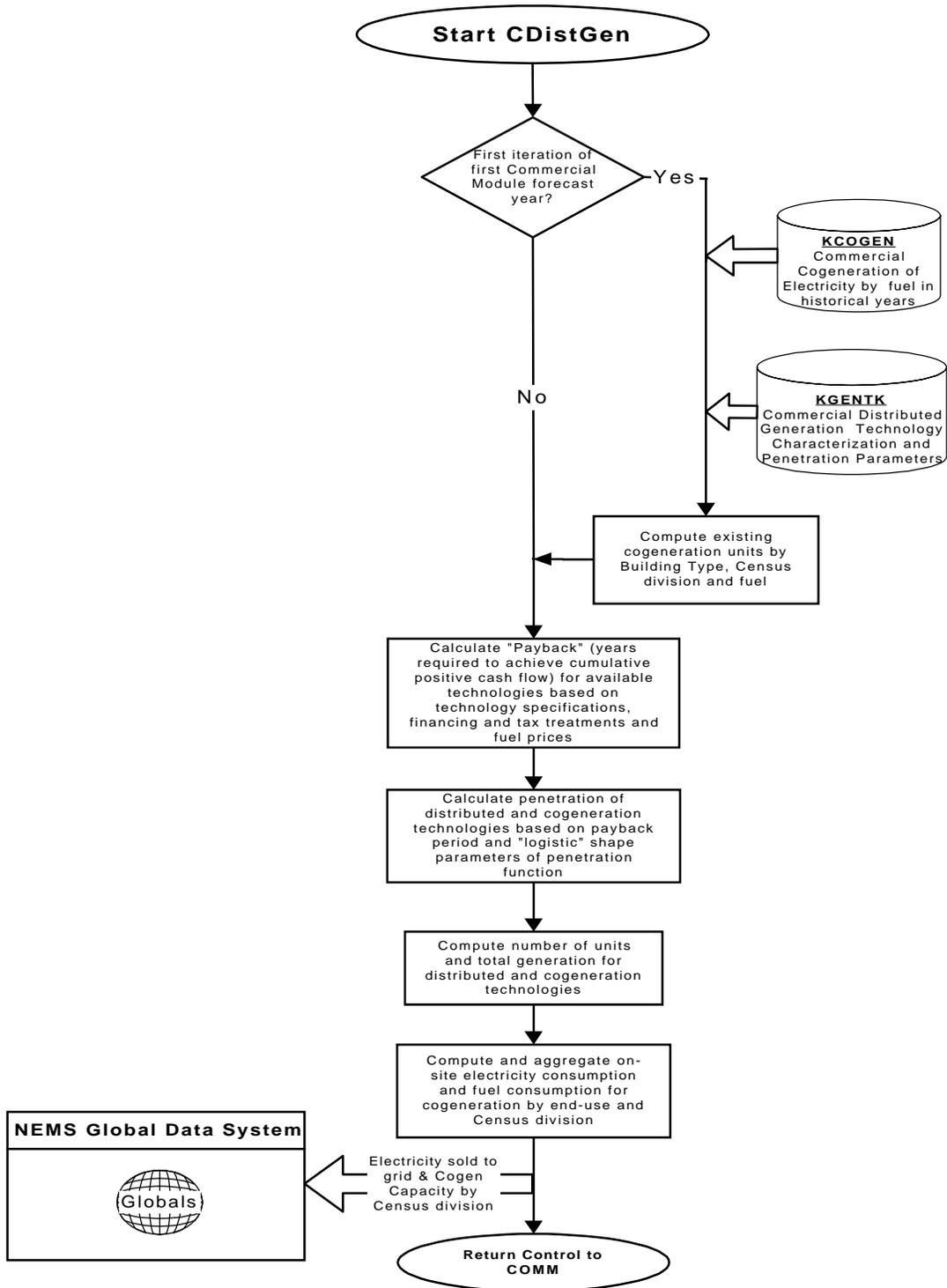


Figure 7. COMTechnologyChoice Calculation Process Flow

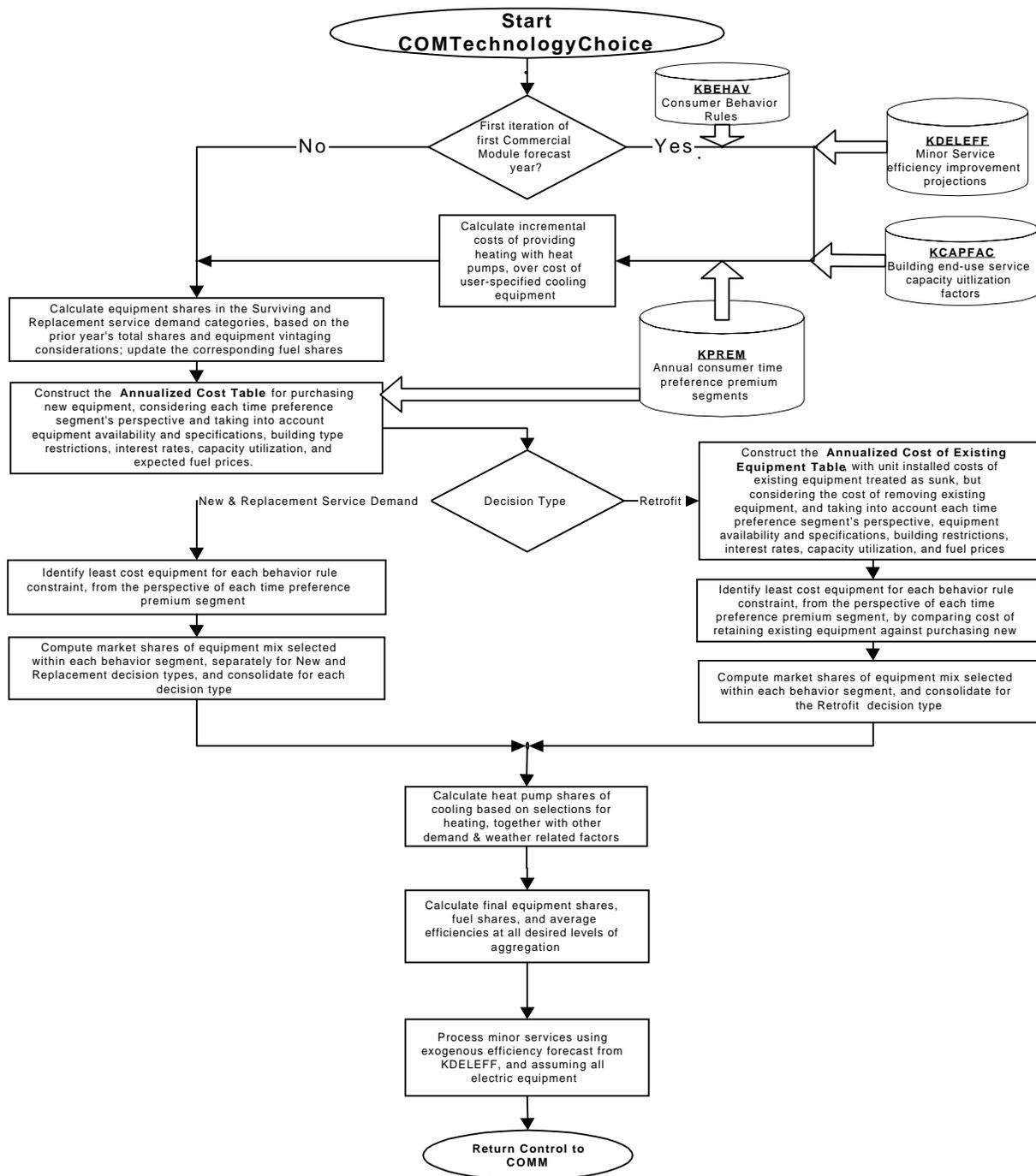


Figure 8. COMConsumption Calculation Process Flow

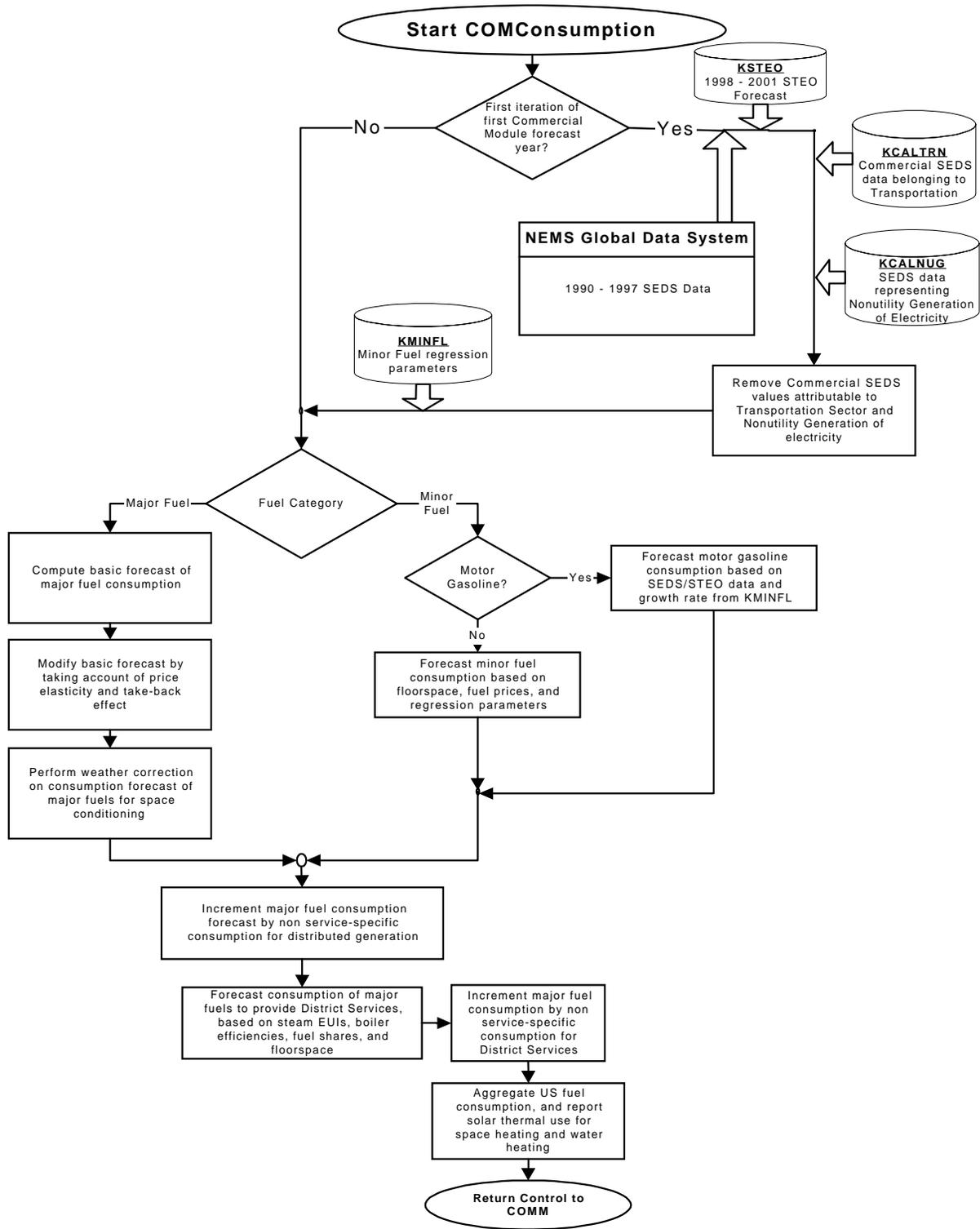
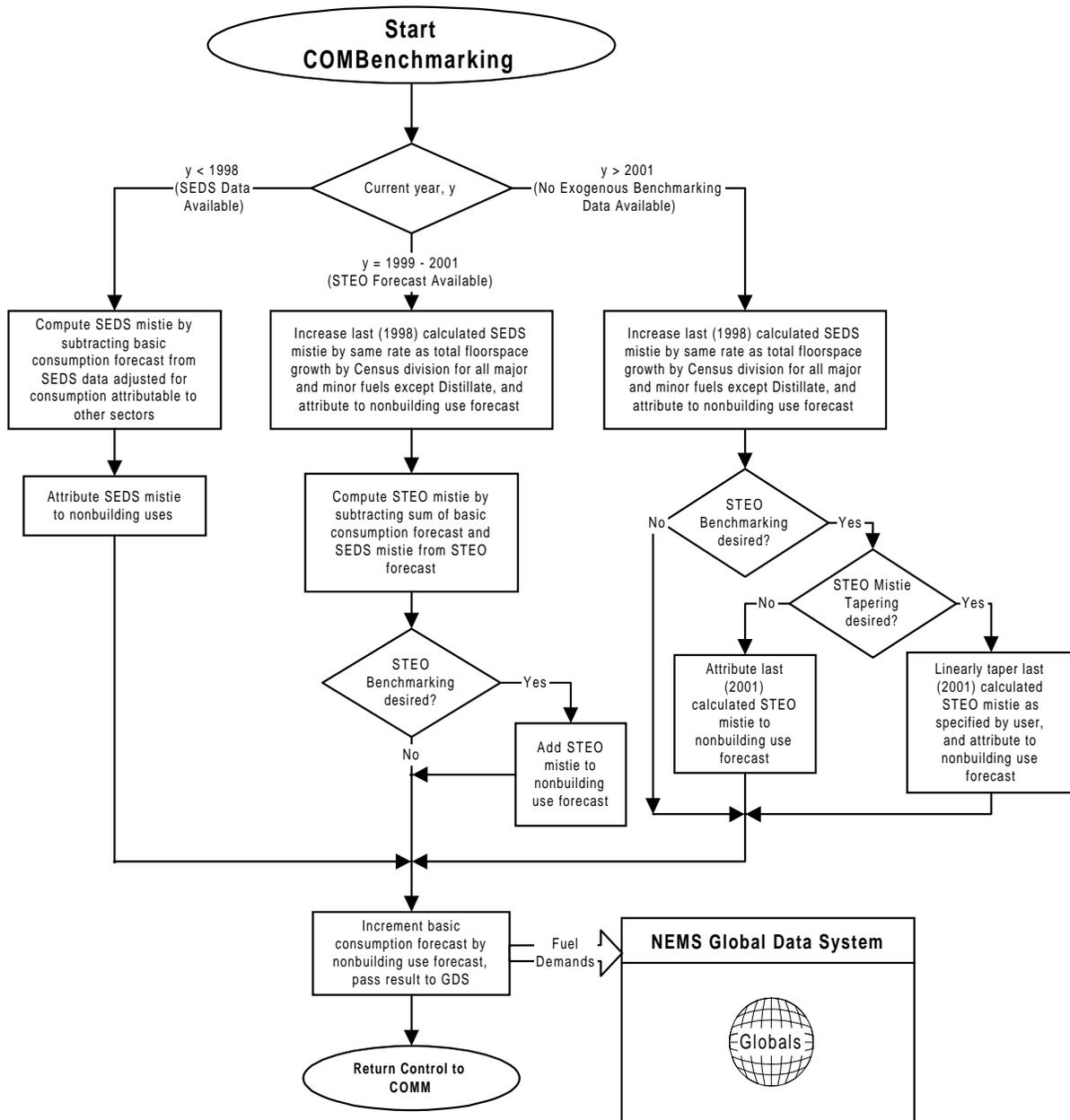


Figure 9. COMBenchmarking Calculation Process Flow



## 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 forecast from the NEMS Macroeconomic Activity Module (MAM) as its primary driver. Many of the parameter estimates used in the Commercial Module, including base year (1995) commercial sector floorspace, are developed from the 1995 Commercial Building Energy Consumption Survey (CBECS) data base. Forecasted total commercial floorspace is provided by the MAM through the MC\_COMMFLSP member of the NEMS Global Data Structure (GDS). Commercial floorspace from the MAM is specified by the 13 building categories forecast by F.W. Dodge of McGraw-Hill, Inc. and supplied through the underlying proprietary model developed by Data Resources Incorporated (DRI). To distinguish the Commercial Module floorspace forecast ultimately produced within the Commercial Module from that provided by the MAM, the latter is referred to as the DRI floorspace forecast in this report.

The Floorspace Submodule first backcasts the 1995 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 forecast period is calculated in a way that causes total floorspace to grow at the rate indicated by the MAM forecast. In the event that the new additions computations produce a negative value for a specific building type, new additions are set to zero.

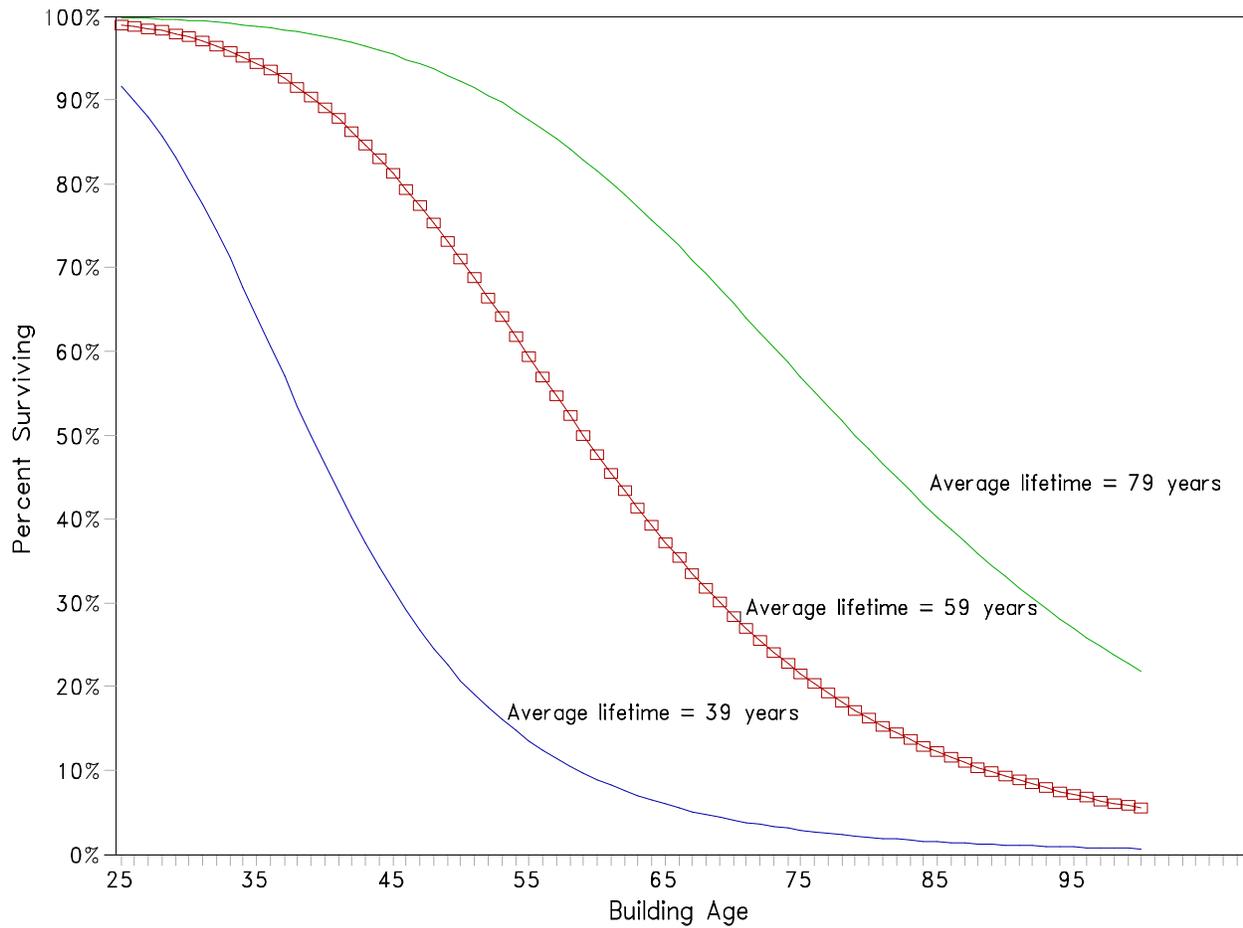
Correspondence with the analysts responsible for the MAM floorspace forecast provided values for the average building lifetime between 40 and 80 years, based on the F.W. Dodge/DRI data provided for the MAM floorspace forecast. The building retirement function used in the Floorspace Submodule depends 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,  $\gamma$ , corresponds to the rate at which buildings retire near their median expected lifetime. The current values for these model inputs are 59 years and 5.3 respectively. 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 as 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:

$$\textit{Surviving Proportion} = \frac{1}{1 + \left( \frac{\textit{Building Age}}{\textit{Median Lifetime}} \right)^\gamma} \quad (15)$$

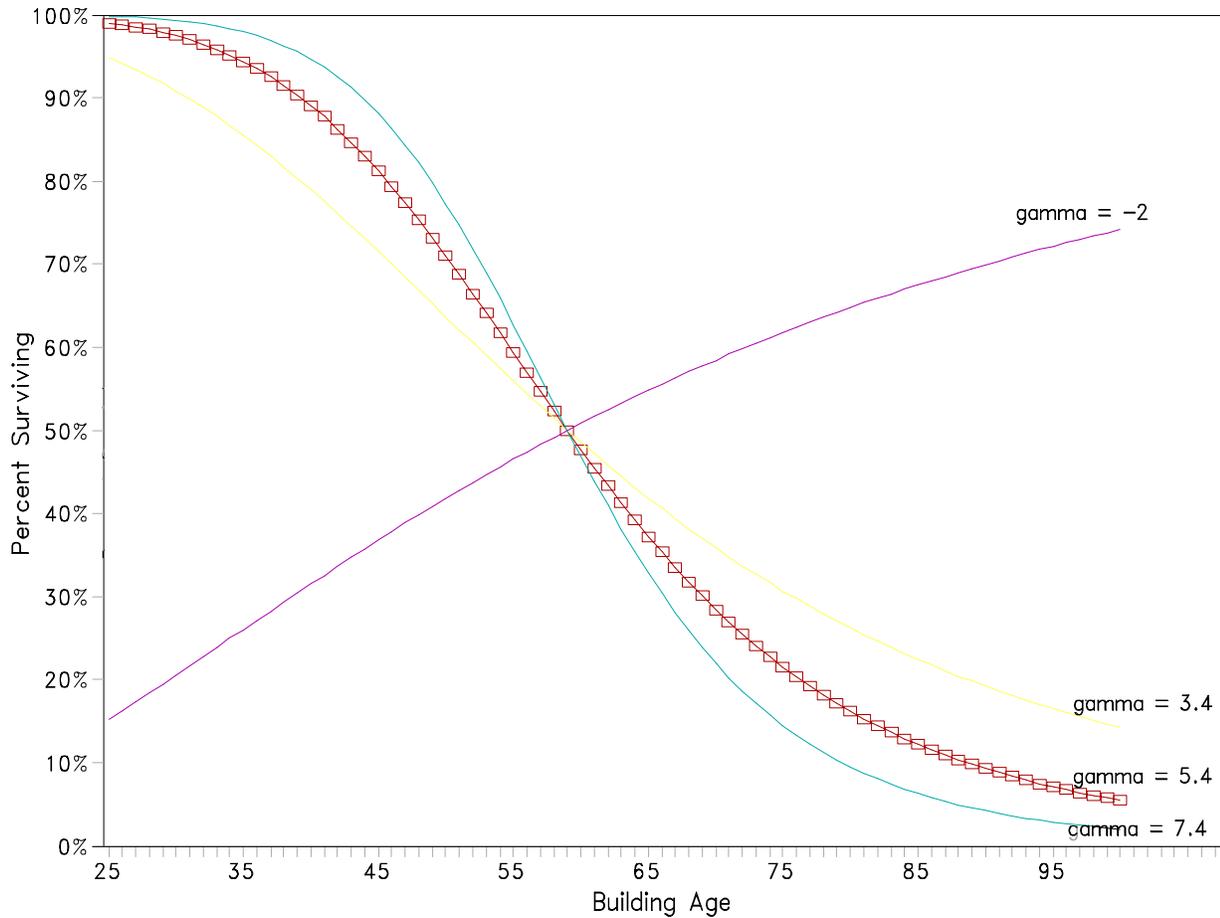
Existing floorspace retires over a longer time period if the median building lifetime is increased or over a shorter time as the average lifetime is reduced as depicted in Figure 10. The user-specified gamma parameter partly determines the shape of the survival rate function that defines the acceleration of the rate of retirement around the average building lifetime. The larger the value of gamma, 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% share mark. This function 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 10. Floorspace Survival Function Sensitivity to Average Building Lifetimes**



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.

**Figure 11. Alternative Gamma Assumptions and Results**



The gamma parameter impacts final energy consumption by determining how gradually the floorspace vintage is retired. A large gamma causes nearly all of the 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.

Surviving floorspace from previous years depends on both the composition of the base year (1995) CBECS stock and all new floorspace added between 1995 and the current year of the forecast. 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 a convolutional approach as follows:

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 15 or B-1 are also known. The relationship of these quantities is given by:

$$\textit{Surviving Stock} = (\textit{Original Stock}) \cdot (\textit{Surviving Proportion}) \quad (16)$$

Dividing the surviving stock by the surviving proportion gives the original stock in the year of construction. This time series of new floorspace is spliced to the new floorspace obtained from the DRI forecast (described below) to produce a total history of new additions to floorspace, starting with the original stock of the oldest CBECS vintage (currently 1825). Surviving floorspace in any given year is then calculated 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 forecast. This is accomplished using the mathematical process known as "convolution," where , for each building type, the time series of new

construction is convolved with the survival function to produce the time series of surviving floorspace, which is evaluated for the current year. This calculation is shown by Equation B-3 in Appendix B.

In order to calculate new additions to floorspace in the current forecast year, the surviving floorspace calculated above is combined with the DRI total floorspace forecast 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 DRI building types. The mapping from the DRI building types to the CBECS building types is represented by a transformation matrix named DRIToCBECS. The thirteen building types forecasted in the MAM are: Amusement, Automotive, Dormitory, Education, Health, Hotel, Manufacturing, Miscellaneous, Office, Public Service, Religious, Store, and Warehouse.<sup>15</sup> New additions are obtained by subtracting the surviving floorspace forecast from the total CBECS floorspace forecast. 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 DRI 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. Therefore, the growth rates by building type obtained in the previous step are uniformly modified within each Census division in such a way that Census division level growth rate agreement between the Commercial Module and the DRI forecast is achieved. 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 forecast 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 forecast of new floorspace. The final value obtained for total floorspace is then given by Equation B-10.

This approach is necessary because the DRI floorspace forecast read from the NEMS Macroeconomic Activity Module is not available as separate forecasts for new additions and existing floorspace stock.

---

<sup>15</sup>The Commercial Module does not use the DRI floorspace forecast for manufacturing buildings provided by the NEMS Macroeconomic Activity Module. Energy consumption in manufacturing buildings is included in the NEMS Industrial Demand Module.

## ***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:

<u>Index</u>	<u>Name</u>	<u>Category</u>
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 (1995) energy use intensities (EUIs), base year efficiencies of equipment, efficiencies of building shells, short-term price elasticities, and weather.<sup>16</sup> Service demands for District 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 conditional demand analysis of the CBECS 1995 consumption survey disaggregated by service, fuel type, building type, and Census division. The concept 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

---

<sup>16</sup>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.

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 service demand intensities are 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:

$$SDI \left( \frac{Btu \text{ out}}{ft^2} \right) = EUI \left( \frac{Btu \text{ in}}{ft^2} \right) \cdot COP_{average} \quad (17)$$

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 1995. The basic calculation illustrated by Equation 17 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; instead, the efficiency of the composite mix of technologies for a given minor service is modeled as evolving relative to its base

year (1995) 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:

$$\text{Service Demand (Btu out)} = \text{SDI} \left( \frac{\text{Btu out}}{\text{ft}^2} \right) \cdot \text{Floorspace (ft}^2\text{)} \quad (18)$$

The computation illustrated above is accomplished in the Commercial Module by evaluating Equations B-22, B-27, B-32, and B-33.

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.<sup>17</sup>

The present shell efficiencies are indexed to the average 1995 values by building type and Census division. The heating shell efficiency indices are modeled as increasing to user-specified values in 2020. For AEO2001, floorspace surviving from the base-year floorstock is assumed to improve a maximum of 4 percent over the 1995 stock average by 2020, and new floorspace is assumed to improve 6 percent by 2020 relative to the efficiency of new construction in 1995. 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

---

<sup>17</sup>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 shell. Changing shell efficiencies impact the demands for Space Heating and Space Cooling services in the following fashion:

$$\textit{Service Demand} = (\textit{Service Demand with 1995 shell}) \cdot (\textit{Shell efficiency index}) \quad (19)$$

The calculations involved in computing the appropriate shell efficiency index and evaluating the expression illustrated by Equation 19 are accomplished using Equations B-23 through B-26 and Equations B-28 through B-30.

The 1995 CBECS data indicated several differences in the proportions of building floorspace receiving services for several major services. The most pronounced differences occurred between newer and older buildings. This effect has been captured, and is accounted for using equation B-31.

While the market for major services is assumed to be saturated, additional penetration of the minor services of Office Equipment (both PC and NonPC) and "Other" is modeled. Forecasts of continuing market penetration are prepared offline as described in Appendix A, and incorporated into the service demand forecast for these minor services using equations B-34 and B-35.

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 forecasts for renewable energy for the commercial sector. 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-36 and B-37.

The short term price elasticity of demand is currently provided for all end-use services. The parameters currently included in the Commercial Module are 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 first referenced in Table A-2. The elasticities 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. 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 17 above, a proportional change in service demand results in the same proportional change in fuel consumption. The service demand elasticity computation is illustrated by Equation B-91. Equation B-91 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.

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 forecast 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-38 and B-39.

### ***Distributed Generation and Cogeneration SubModule***

The Distributed Generation and Cogeneration 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 cogeneration, municipal solid waste and wood generators, and hydroelectric.

Initialization of the base year cogeneration by technology, Census division and building type are developed from data contained in the most recent year's version of the Form EIA-860B, Annual Electric Generator-Nonutility, database. 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 860B) divided by the average generation of electricity for the particular technology to which the fuel type was mapped (Equation

B-134). The estimated units then form the installed base of cogeneration equipment which 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-136 and B-137).

For years following the base year, distributed generation technology penetration rates are estimated by Census division and building type 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% when investments pay back in 1 year or less. That is, up to 30% of new construction in any year can potentially include a specific distributed generation technology. For retrofitting distributed generation into existing floorspace, penetration is limited, by assumption, to a much smaller rate. The limit is the lesser of 0.25% or the penetration rate into new construction divided by 50. The limit is in effect if penetration into new construction exceeds 12.5%.

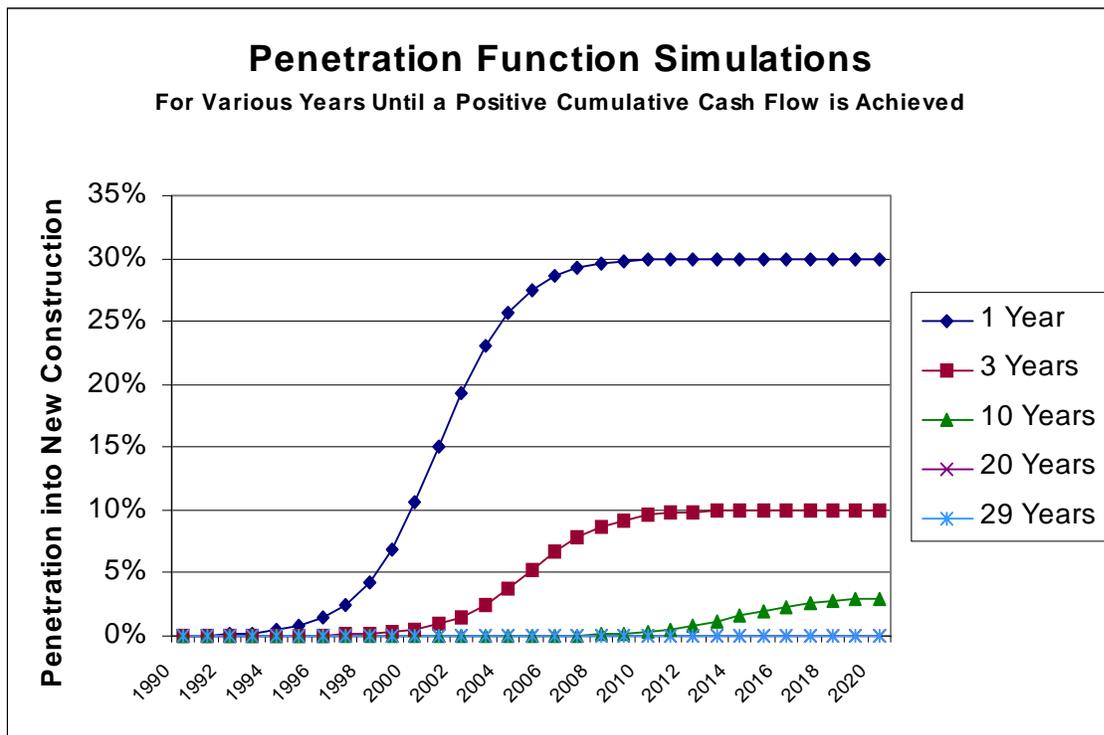
For new construction, penetration rates are a direct function of the number of years required to achieve a cumulative positive cashflow for the investment. This approach is related to, but different from calculating the estimated “years to simple payback” concept. Simple paybacks are merely the investment 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-125 through B-149 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 penetration function for new construction has 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-147). 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. The figure below represents the penetration function under a maximum assumed penetration of 30% for new construction.

**Figure 12. Penetration Function for Distributed Generation Submodule**



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.”<sup>18</sup> 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-125). 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 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.

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 water heating energy use. 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.

---

<sup>18</sup>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.

## ***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 six distinct 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 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 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 with constant returns to scale. This means that there is 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.) to develop a composite score for the technology. Choices among the technologies are then made by minimizing the annualized cost. The annualized cost represents the discounted flow of all O&M, capital, and fuel costs of the technology over its lifetime. The technology is chosen by minimizing the annualized cost per unit service demand (subject to constraints on the set of potential technologies represented by the behavior rules discussed below). 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:

$$\begin{aligned}
 \frac{\textit{Annualized cost}}{\textit{unit of delivered service}} &= (\textit{annuitized purchase \& installation cost component}) \\
 &+ (\textit{yearly O\&M component}) \\
 &+ (\textit{expected yearly fuel cost component})
 \end{aligned}
 \tag{20}$$

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 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-46.

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 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.

The actual calculation of the annualized cost for comparison of candidate technologies is performed using Equation B-51. 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-47 and B-48, uses the same shell efficiency indices calculated in the Service Demand Submodule. The effective hurdle (implicit discount) rate used in Equation B-51 is given by Equations B-49 and B-50 and discussed on pages 80 and 81.

The costs that are relevant to the consumers and the menu of technologies vary for different consumers and different choices. Therefore, a distribution of technologies, rather than a single technology, is chosen when the decisions of various consumers for various decisions are consolidated. A distribution is more representative of consumer response than a forecast which assumes 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 10 and described in greater detail below.

**Table 10. Array of Technology Choices and Consumer Behaviors**

<b>Decision Type→ Behavior Rule ↓</b>	<b>New</b>	<b>Replacement</b>	<b>Retrofit</b>
<b>Least Cost</b>	New Equipment, Least Cost Rule	Replacement Equipment, Least Cost Rule	Retrofit Decision, Least Cost Rule
<b>Same Fuel</b>	New Equipment, Same Fuel Rule	Replacement Equipment, Same Fuel Rule	Retrofit Decision, Same Fuel Rule
<b>Same Technology</b>	New Equipment, Same Technology Rule	Replacement Equipment, Same Technology Rule	Retrofit Decision, Same Technology Rule

**Behavior Rules**

The NEMS Commercial Sector Demand Module simulates this 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. 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 1995 data is combined with other data characterizing consumer behavior obtained from published literature to develop the behavior rule proportions incorporated in the Module. Changing these proportions impacts final consumption estimates.

Supporting data from CBECS 1995 includes building stock ownership patterns for 1995. This data is presented in Table 11. 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.

**Table 11. Floorspace Ownership and Occupancy**

	Total			Nongovernment		Nongovernment		Nongovernment		Self
	Floorspace (MM sq. ft.)	Government (MM sq. ft.)	Owned percent	Owned (MM sq. ft.)	Owner Occupied (MM sq. ft.)	percent	Non-owner Occupied (MM sq. ft.)	percent	Built percent	
Assembly	6,741	1,552	23.0%	5,189	4,930	73.1%	259	3.8%	92.0%	
Education	7,740	5,209	67.3%	2,531	2,397	31.0%	134	1.7%	99.0%	
Food Sales	642	0	0.0%	642	535	83.3%	107	16.7%	50.0%	
Food Service	1,352	77	5.7%	1,275	1,127	83.4%	148	10.9%	50.0%	
Health Care	1,642	443	27.0%	1,199	1,167	71.1%	32	1.9%	85.0%	
Lodging	3,618	350	9.7%	3,268	2,980	82.4%	288	8.0%	80.0%	
Mercantile/Service	12,728	870	6.8%	11,858	8,213	64.5%	3,645	28.6%	25.0%	
Office	11,170	1,372	12.3%	9,798	7,348	65.8%	2,450	21.9%	30.0%	
Warehouse	8,481	645	7.6%	7,836	5,425	64.0%	2,411	28.4%	50.0%	
Other	4,658	1,558	33.4%	3,100	2,879	61.8%	221	4.7%	50.0%	
TOTAL:	58,772	12,076	20.5%	46,696	37,001	63.0%	9,695	16.5%	54.9%	

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 11 and this discussion.

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

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 given 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 which 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.

Previously, 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 first determine the mix of equipment and corresponding fuel shares represented in the Replacement and Retrofit Decision Types. This is accomplished by Equations B-40 through B-44 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-53. Consumers using the same fuel behavior rule choose from among current technologies which use the same fuel as in surviving buildings (buildings that do not retire). Identification of the least cost equipment for each fuel from the perspective of each consumer time preference segment is made using Equation B-54. 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-57. Similarly, the identification of least cost models for each technology for the consumers following the same technology rule is illustrated by Equation B-55. 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-59.

For equipment replacement decisions, consumers using the least cost behavior rule choose from among all current technologies, as illustrated again by Equation B-53. 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-58. 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-60.

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 20 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 annualized cost of retaining existing equipment is given by Equation B-63. 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-47 and B-48, incorporating the effects that building shell improvements have on fuel costs, and the effective hurdle rate given in Equations B-49 and B-50.

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-51 against the cost of retaining the existing equipment as expressed by Equation B-63, and choosing the least cost result, as illustrated by Equation B-64. 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-65. 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 AEO2001 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-66. Alternatively, all consumers using the same technology behavior rule may be assumed to retain their existing equipment, as indicated by Equation B-69. 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 time preference held by the consumer. These time preferences are discussed below in preparation for the description of consolidation of equipment choices to obtain the final equipment market shares.

### **Time Preferences**

Consumers have different preferences on the value of money over time (the value of money now versus the value of money at some future time). Consumers' discount rates can be tied to many attributes of personal preference or in many cases to age cohort. For example, older consumers may have a higher time preference premium because they may have a shorter expected time over which they expect to enjoy the money.

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 time preferences as input. This is a discrete distribution; it takes the form of a list of real time preferences (premiums to the risk-free interest rate), and a proportion of commercial consumers corresponding to each time preference. The time preference distribution is modeled independently of the behavior rules. The time preference results in differences in consumer preferences between capital costs (paid initially) and fuel and O&M costs (incurred over the lifetime of the equipment). The value of the consumer's 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 time preference premium, and expected physical equipment lifetime. The sum of the 10-year Treasury bond rate and the consumer 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 distribution of the consumer's interest rate premium impacts results in several aspects. 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 time preferences regarding the adoption of a specific technology. For AEO2001, the distribution of consumer time preference premiums is assumed constant over the forecast horizon under conditions of stable fuel prices. 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.

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 (1995), 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-49 and B-50. Parameter assumptions for AEO2001 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 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 time preference segment to calculate market shares of equipment within each behavior rule segment of each decision type. Since a given 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 time preference segment that selected that equipment. This is the calculation performed by Equations B-56 through B-60 and B-67 through B-69, 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-61, B-62, and B-70 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 12.

**Table 12. 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 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 be purchased primarily 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-45.

During the technology choice process for satisfying space cooling service demands, heat pumps are excluded from selection. Instead, market shares of cooling service demand satisfied by the heat pumps selected to provide space heating are explicitly computed. This is accomplished by assuming that the ratio of cooling to heating delivered by a heat pump over the course of the forecast 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-71. 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-72 through B-74.

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-75 within the decision type segments by end-use, fuel type, building type, and Census division, and by B-77 consolidated across decision types. Equations B-83 through B-85 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-76, B-79 through B-82, and nationally by end-use and fuel using Equation B-86. 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 1995 average efficiencies for the minor services are indexed to unity, and an exogenous forecast of minor service efficiency improvement is employed. 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-87. Minor services are further assumed to use only electricity, and to possess identical average efficiencies for all decision types and buildings within a given Census division and year, as illustrated by Equation B-88.

### **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 and technology cost trend parameters are specified exogenously. Equipment availability pertains to the set of technologies currently in the marketplace during a particular forecast year; not all available technologies are economically feasible, and therefore may not be selected. The menu of potential technologies includes technologies which are currently under development to be introduced over the forecast 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 forecast period. As an example, assume that a new high efficiency piece of equipment becomes available in a specific forecast 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 over the forecast horizon.

The 1995 initial historical market shares are based on an analysis of CBECS 1995 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 is available constrains the technology choice menu for all decision types. For example, a distillate-fuel fired furnace currently available may no longer be available in 2001 due to federally mandated minimum equipment efficiency standards.

Starting with AEO2000, 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 technologies 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 a technology's availability 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 technology will not be shifted back to its original availability date. In addition, shifts are limited to a lesser number of years for nearer term technologies (e.g., those projected for 2005) to ensure that future technologies can not become available before the persistent price change is projected to occur. Equations B-122 through B-124 illustrate the calculations needed to move a technology's availability date forward through price-induced technology change. Although no price-induced change would have been expected using AEO2001 reference case fuel prices, the parameter was set to 0 years for the AEO2001 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 forecasts the consumption of fuels to provide district services in the commercial sector, accounts for the net effects of distributed generation and cogeneration of electricity 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 forecast 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-89, makes use of the definition of average efficiency to obtain the forecast of consumption by fuel, end-use, building type 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 forecast 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-90.

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 (1995), 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 forecast. 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-89; that is, a percentage change in service demand corresponds to the same percentage

change in fuel consumption. The first term in equation B-91 shows the calculation and application of the short-run price elasticity of demand to modify the basic consumption estimate obtained by equation B-89.

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 which 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-91. Because these modifications to the basic consumption estimate are each multiplicative, equation B-91 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.

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 forecast period, and differences between the base year (1995) weather and "average" weather anticipated for future years. The basis for the weather correction is the number of heating and cooling degree days by Census division for the years 1990 through 1999, together with the long term average of each. Because 1995 is the base year for the key Commercial Module parameters, the basic forecast 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 1995. This is accomplished using a multiplicative factor equal to the ratio of the appropriate degree days, as shown by equation B-92. Values for 2000 have been extrapolated using data through August of that year. Years after 2000 are assumed to exhibit the long-term average number of heating and cooling degree days, by Census division.

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 forecast 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

services and "non-building" consumption (consumption in the commercial sector not attributable to end-uses within buildings, such as street lighting).

With the exception of motor gasoline, consumption of the minor fuels is forecast using elasticities derived from historical minor fuel consumption and pricing data. The historical data, obtained from the State Energy Data System (SEDS), spans the 23 year period from 1970 to 1992, for each Census division. The estimated elasticities are applied to the forecasted minor fuel price to yield a forecasted minor fuel EUI. Combining this EUI with the forecasted commercial floorspace produces the forecast of minor fuel consumption. The entire calculation is given by equation B-106.

Motor gasoline consumption is forecast by replicating SEDS data for the years 1990 through 1997, followed by the Short Term Energy Outlook (STEO) forecast for 1998 through 2000, after which a growth rate derived from the SEDS historical analysis is applied to obtain the forecast for future years. The approach is shown by equations B-107 and B-108.

The End-Use Consumption Submodule also accounts for nonutility generation of electricity by the commercial sector using distributed generation and cogeneration technologies, together with the quantities of fuels consumed to accomplish electricity generation and cogeneration of heat as described in the Distributed Generation and Cogeneration section. End-use consumption of purchased electricity is reduced as given by equations B-93 through B-95 to reflect the use of self-generated electricity. Equation B-96 illustrates reduction in space and water heating consumption through use of heat generated by cogeneration technologies. Equation B-97 accounts for fuel consumption by distributed generation and cogeneration technologies.

The final component of the forecast assembled by the End-Use Consumption Submodule is an estimation of the quantities of fuel consumed in order to provide the district services of space heating, space cooling, and water heating. District 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 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 services, together with the floorspace forecast, to produce the forecast of fuel consumption for district services, as shown by equations B-98. Price elasticity considerations and the weather correction are applied to district services fuel consumption in the same manner as they are applied to direct fuel use for end-use services as shown by equation B-99.

The consumption forecast by Census division, fuel, end-use service, and building type is incremented by the district service consumption estimate just described, as shown by equation B-101. Aggregation of this result across end-use services and building types yields the forecast of fuel consumption by fuel and year at the Census division level required by the other NEMS modules, as shown by equation B-110. Another aggregation across fuels and Census divisions is performed to obtain the national-level forecast 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-111. 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, that of nonbuilding consumption, is calculated in the Benchmarking Submodule, described in the next section.

### ***Benchmarking Submodule***

The Benchmarking Submodule reconciles the fuel consumption forecast 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 forecast. Additionally, the Benchmarking Submodule provides an option for considering results from EIA's Short Term Energy Outlook (STEO) for the near term immediately beyond the last year of SEDS data availability. Definitional differences between SEDS and the Commercial Buildings Energy Consumption Survey (CBECS), upon which the Commercial Sector Demand Module is based, are used to construct a forecast of commercial sector fuel consumption not attributable to end-uses within buildings.

Equation B-112 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 forecast and the SEDS data is attributed to fuel consumption for nonbuilding uses, as shown by equation B-113. This assignment is performed during each year of the forecast 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 reliable estimates of SEDS data are available for an additional year beyond the latest published SEDS results, and are used in the same manner as published SEDS data.

After the final year of SEDS data availability, fuel consumption for nonbuilding uses is forecast to grow at the same rate as commercial floorspace. This expectation follows from the observation that, while not representing fuel

consumption within buildings, the nonbuilding uses are generally associated with commercial buildings, as in the case of exterior lighting of parking lots. The forecast of SEDS-based consumption of major and minor fuels other than distillate and residual fuel oil for nonbuilding uses beyond the last year of SEDS data availability is shown by equation B-115. Nonbuilding use of distillate and residual fuel oil 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-117.

An option is present in the Commercial Sector Demand Module to activate benchmarking to that portion of the STEO forecast immediately following the last year of SEDS 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 forecast. If selected, the benchmarking is incremental; that is, it is calculated based on the forecast produced after benchmarking to SEDS. For years covered by the short-term STEO forecast, the calculation of the discrepancy between the SEDS-benchmarked forecast and STEO is given by equation B-114 for the major and minor fuels except distillate and residual fuel oil. Equation B-116 gives the corresponding calculation for distillate and residual fuel oil. Equation B-118 shows the addition of the STEO-based incremental component of nonbuilding 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 forecast beyond the last year of STEO data must also be selected. The simplest option is to retain the STEO component of nonbuilding use calculated for the last year of STEO data availability, and apply it to all future years of the forecast period. Alternatively, the STEO component of nonbuilding 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-119. B-120 illustrates the optional addition of a STEO-based component of nonbuilding consumption to that based on SEDS, for forecast years after the final year of STEO data availability. For AEO2001, the option to benchmark to years 1998 through 2000 of the STEO forecast was chosen with the STEO component of nonbuilding use retained for all future years of the forecast period.

Addition of the forecast of fuel consumption for nonbuilding uses to that produced by the End-Use Consumption Submodule for end-uses within buildings completes the forecast of commercial sector fuel consumption, as shown by equation B-121.

# 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 Cogeneration Submodule are found at the end of Table A-1. Following Table A-1 are profiles of the data items. Each profile describes the data sources, analytical methodologies, and parameter estimates corresponding to the table.

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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
ACE	B-63	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 time preference premium. Calculated for each Census division and building type during each iteration of each forecast year. Incorporates building capacity utilization factor, yearly operating and maintenance cost, annualized fuel costs, interest rate forecast, and consumer 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	<p>Non-lighting, non-ventilation: Constant 1998 dollars / (thousand Btu out per hour) / year</p> <p>Lighting: Constant 1998 dollars / thousand lumens / year</p> <p>Ventilation: Constant 1998 dollars / thousand CFM</p>
AE	B-76	Technology Choice	Average equipment efficiency by major fuel, decision type, service, building, and Census division.	Calculated variable	<p>Non-lighting, non-ventilation: Btu delivered / Btu consumed (=Btu out / Btu in)</p> <p>Lighting: lumens / watt</p> <p>Ventilation: thousand CFM-hrs air delivered / thousand Btu consumed</p>

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
AnnualCostTech	B-51	Technology Choice	Annualized life cycle cost of a technology per unit of delivered service, by technology class, technology vintage, and consumer time preference premium. Calculated for each Census division and building type during each iteration of each forecast year. Incorporates building capacity utilization factor, annualized unit installed capital cost, yearly operating and maintenance cost, annualized fuel costs, interest rate forecast, and consumer 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 1998 dollars / (thousand Btu out per hour) / year  Lighting: Constant 1998 dollars / thousand lumens / year  Ventilation: Constant 1998 dollars / thousand CFM
AverageEfficiency	B-79	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
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
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 KPARAM	Unitless
BehaviorShare	B-61	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-51	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
CBECSEFIRSpC	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)
CBECSEyear	B-2	COMM	Survey year of CBECS data used as base year data for the Commercial Module. CBECSyear = 1995.	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
CMAvgAge	B-1	Floorspace	Median building lifetime by building type b.	Input from file KBLDG	years
CMFinalEndUse	B-110	Consumption	Consumption of fuels across end-uses, including cogeneration and district services, by fuel type (major, minor, and renewable), Census division, and year.	Calculated variable	Trillion Btu
CMFirstYr	B-39	COMM	Index of first year of forecast. 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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
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 CBECYear.	Calculated variable	Million sq ft
CMNonBldgUse	B-113	Benchmarking	Nonbuilding fuel consumption by Census division, fuel, and year.	Calculated variable	Trillion Btu
CMnumBldg	B-36	Service Demand	Number of Commercial Module building types. Current value is 11.	Parameter	Unitless
CMnumMajFI	B-20	Service Demand	Number of Commercial Module major fuels. Current value is 3.	Parameter	Unitless
CMnumVarSDI	B-31	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
CMSEDS	B-112	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 1990-1997). Similar data from the STEO forecast is present for the years 1990+MSEDYR through 1989+KSTEOYR (currently 1998 through 2000).	Module input from Global Data Structure and file KSTEO	Trillion Btu

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
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 buildings.	Calculated	Million square feet
CMUSAvgEff	B-86	Technology Choice	National average equipment efficiency by end use service, fuel, and forecast year.	Calculated Variable	Btu delivered / Btu consumed
CMUSConsump	B-104	Consumption	U.S. total fuel consumption 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 =1995.	Input from file KINTENS	Thousand Btu consumed / sq ft / year
ComSTEOBM	B-118	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-46	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
DecAvgEff	B-80	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 forecast 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-119	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-83	Technology Choice	Fuel share of service, by decision type, Census division, major end-use service, major fuel type, and forecast year.	Calculated variable	Unitless

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
DegreeDays	B-92	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. Data is available from 1990 through the last STEO forecast year used by NEMS, with the year index KSTEOYR. Data for the year with index KSTEOYR provides the average heating and cooling degree days for normal years. The data is used to perform a weather adjustment to the consumption forecast in the Consumption subroutine, and to determine the relative amounts of heating and cooling supplied by heat pumps (Equation B-57).	Input from KDEGDAY	Degrees Fahrenheit x day
DistServBoilerEff	B-98	Service Demand	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-98	Consumption	Consumption of fuels to provide district services, by Census division, building type, fuel, year, and district service.	Calculated	Trillion Btu in
DistServFuelShr	B-98	Service Demand	Proportions of district service steam energy generated by each fuel type, by fuel and building type.	Input from file KDSFS	Unitless
DistServSteamEUI	B-98	Service Demand	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
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
EffectHurdle	B-50	Technology Choice	Effective hurdle (implicit discount) rate after considering effects of fuel price changes for the current Census division, major service, fuel, time preference level, and forecast year.	Calculated variable	Unitless
EffGrowthRate	B-87	Technology Choice	Average annual growth rate of minor service efficiencies.	Module input from KDELEFF	Unitless
EndUseConsump	B-89	Consumption	Forecasted consumption of fuel by end-use service, major fuel, building type, Census division, and forecast year.	Calculated variable	Trillion Btu
ExistImprov	B-23	Service Demand	Heating building shell efficiency improvement for existing buildings achieved by the year 2020 as a proportion relative to the CBECS base year (currently, 1995).	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-102	Consumption	Final end-use consumption of major and minor fuels, by Census division, building type, fuel, and forecast year, summed across services, including district services and electricity cogeneration.	Calculated variable	Trillion Btu in / year

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
FirstNonBenchYr	B-119	Benchmarking	Final year of time span over which to taper down the final (currently 2000) STEOMistie optionally used in benchmarking. If STEO benchmarking option is selected, and the STEO taper option is selected, then the forecast adjustment for FirstNonBenchYr and future years due to mismatch with STEO during earlier years becomes zero.	Input from KPARAM (into temporary intermediate variable named LastDecayYr)	Calendar year
FS	B-75	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
FuelShareofService	B-77	Technology Choice	Forecasted 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-46	Technology Choice	Shape parameter corresponding to the rate of price decline in the cost trend function	Input from KTECH	Unitless
HeatPumpCoolingSD	B-72	Technology Choice	Amount of cooling service demand satisfied by heat pumps by decision type (new replacement, and retrofit).	Calculated variable	Trillion Btu out

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
Hurdle	B-49	Technology Choice	Hurdle (implicit discount) rate. The sum of the ten-year treasury bond rate and the time preference premium for the current major service, time preference level, and forecast year.	Calculated variable	Unitless
HurdleElas	B-50	Technology Choice	Hurdle (implicit discount) rate elasticity parameter by Census division, service and fuel.	Input from file KHURELA	Unitless
IFMAX	B-124	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
KEqCost	B-46	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 1998 dollars / (thousand Btu out per hour) / year  Lighting: Constant 1998 dollars / thousand lumens / year  Ventilation: Constant 1998 dollars / thousand CFM

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
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 EUs 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 EUs vary by building type.	Calculated variable	Unitless
KSTEOYR	B-114	Consumption	Index of the last year of available STEO data. Currently 11, corresponding to 2000.	Parameter	Unitless
LCMSNR	B-56	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-67	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
MarketPenetration	B-34	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 forecasted saturation level.	Input from file KOFFPEN	Unitless

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
MC_COMMFLSP	B-4	Floorspace	NEMS Macro Module forecast of total commercial floorspace, by Dodge/DRI building type, Census division, and forecast year.	Input from NEMS Macroeconomic Activity Module	Billion square feet
MC_REALRMGBLUS	B-49	Technology Choice	Yield on U.S. Government ten year bonds.	Input from NEMS Macroeconomic Activity Module	Percent
MinFuelAlpha	B-106	Consumption	Elasticity parameter used in the calculation of minor fuel consumption.	Input from file KMINFL	Natural logarithm of (MMBtu/sq ft) / (1987\$/MMBtu)
MinFuelBeta	B-106	Consumption	Elasticity parameter used in the calculation of minor fuel consumption.	Input from file KMINFL	Unitless
MS	B-61	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 forecast year.	Calculated variable	Unitless
MSEDYR	B-112	Benchmarking	Index of the final year of available SEDS data. Currently 6, corresponding to 1995.	NEMS system parameter	Unitless index
NewImprov	B-28	Service Demand	Heating building shell efficiency improvement for new buildings achieved by the year 2020 as a proportion relative to the CBECS base year (currently, 1995).	Input from file KSHEFF	Unitless

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
NewServDmd	B-27	Service Demand	Service demand in new commercial floorspace by Census division, building type, end-use service, and year.	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-73	Technology Choice	Market share adjustment factor for space cooling equipment other than heat pumps.	Calculated variable	Unitless
NSD	B-71	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
Pr	B-50	Technology Choice, Consumption	Commercial sector fuel prices, by fuel (major and minor), Census division, and forecast year. Electricity prices are also by end-use service.	Input from appropriate NEMS supply sector modules.	Constant 1987 dollars per million Btu (converted to 1998 dollars per million Btu for technology choice calculations)

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
PrevYrAverageEfficiency	B-87	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-57	Technology Choice	Forecasted 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-38	Technology Choice	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-122	Technology Choice	Commercial sector national fuel prices, by fuel (major), and forecast 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-122	Technology Choice	Comparison of three year average fuel price to baseyear fuel price, by fuel (major), and forecast year. Used to determine price-induced technological change.	Calculated variable	Unitless
ReplacementFuelShareofService	B-44	Technology Choice	Fuel shares of that portion of service demand requiring replacement due to equipment failure, by fuel.	Calculated	Unitless

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
ReplacementShareofService	B-43	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-38	Service Demand	Service demand in surviving floorspace that becomes unsatisfied in the current forecast year due to equipment failure, by Census division, building type, end-use service, and year.	Calculated variable	Non-lighting, non-ventilation: Trillion Btu out  Lighting: Billion lumen years out  Ventilation: Trillion CFM hours
RetroCostFract	B-63	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-71	Technology Choice	Service demand in surviving floorspace that becomes unsatisfied in the current forecast 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-71	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
SEDSMistie	B-112	Benchmarking	Difference between historical data on fuel consumption derived from State Energy Data System (SEDS), and the CBECs-based Commercial Module forecast, 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 1995) 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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
ServDmdSurv	B-39	Service Demand	Service demand in existing ( <i>i.e.</i> , 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-31	Service Demand	Proportion of building floorspace that receives end-use service, by building type, service, and whether the buildings are newly-constructed (post-1989) or existing (pre-1990).	Input from KVARSDI	Unitless
SFMSN	B-57	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-58	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-68	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation			Calculated variable	Unitless
ShellEffFactor	B-47	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 1995). 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 1995). 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	Unitless
Shiftyears	B-123	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 Technological 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
SolarRenewableContrib	B-111	Service Demand	The amount of service demand satisfied by solar energy, by Census division, solar service, and forecast year.	Input from file KRENEW	Non-lighting: Trillion Btu out  Lighting: Billion lumen years out

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation			Calculated variable	
SSD	B-71	Service Demand	Service demand in existing ( <i>i.e.</i> , 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-118	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 KPARAM.	NEMS system parameter	Unitless
STEOmistie	B-114	Benchmarking	Difference between short-term forecast of fuel consumption given by the Short Term Energy Outlook (STEO), and the CBECs-based Commercial Module forecast after benchmarking to SEDS using SEDSMistie, by fuel (major and minor) and Census division.	Calculated variable	Trillion Btu in
STEOtieDecayFactor	B-119	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-59	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
STMSR	B-60	Technology Choice	Equipment market shares of service demand within the same technology behavior segment of the replacement purchase decision type, by technology class and model number (t,v).	Calculated variable	Unitless
STMSRet	B-69	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-69	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 KPARAM	Unitless
SurvFloorTotal	B-3	Floorspace	Total surviving commercial floorspace by Census division, building type, and year.	Calculated variable	Million sq ft
SurvivingFuelShareofService	B-42	Technology Choice	Fuel shares of surviving service demand after adjustment for equipment failure by Census division, building type, major service, major fuel, and year.	Calculated	Unitless
SurvivingShareofService	B-41	Technology Choice	Surviving equipment market shares of surviving service demand after adjustment for equipment failure, by Census division, building type, major service, equipment, and year.	Calculated	Unitless

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
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 first becomes 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-38	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
TechCost	B-45	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 1998 dollars / (thousand Btu out per hour) / year  Lighting: Constant 1998 dollars / thousand lumens / year  Ventilation: Constant 1998 dollars / thousand CFM

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
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-38	Technology Choice	Median life expectancy of equipment, in years, by technology class and vintage (model).	Module input from KTECH	Years; Unitless where used as exponent
TechShareofService	B-79	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 forecast 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 1995). Calculated based on KTECH market shares, building restrictions, base year EU's, and other considerations.	Calculated variable	Unitless

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
TimePrefPrem	B-49	Technology Choice	Consumer time preference interest rate premium which is applicable to a proportion of the population given by TimePrefProp, by major service, time preference level, and forecast year.	Input from file KPREM	Unitless
TimePrefProp	B-56	Technology Choice	Proportion of consumers who fall into given categories of consumer time preference levels (implicit discount rates). The time preference premiums applicable to each level are given by TimePrefPrem.	Input from file KPREM	Unitless
TSD	B-77	Technology Choice	Total service demand, defined as the sum of service demand for existing floorspace that continues to be satisfied by non-failed equipment (SSD), service demand for existing floorspace that becomes unsatisfied because of equipment failure (RSD), and service demand from new floorspace (NSD); by Census division, building type, end-use service, and year.	Calculated Variable	Non-lighting, non-ventilation: Trillion Btu out  Lighting: Billion lumen years out  Ventilation: Trillion CFM hours
Xprice	B-52	Technology Choice	Expected fuel prices for the commercial sector, by major fuel, Census division, and forecast year.	Input from the NEMS Integrating Module or calculated, at user's option.	Constant 1987 dollars per million Btu (converted to 1998 dollars per million Btu for technology choice calculations)
Years Forward	B-124	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

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
alpha	B-147	Distributed Generation	Parameter controlling shape of the logistic penetration function. Dimension: technology.	Input from file KGENTK	Unitless
annualkwh	B-132	Distributed Generation	Represents annual system kWh generation for the specific technology and vintage being analyzed.	Computed	KWh
avail	B-134	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
baseyrfuelcost	B-140	Distributed Generation	Initial year fuel costs for operating the generation technology. Calculated from the fuel price and fuel input	Computed	1999 Dollars
baseymaintcost	B-144	Distributed Generation	Annual maintenance cost per kw. Dimensions: technology and vintage.	Input from file KGENTK	1999 dollars/kw
beta	B-125	Distributed Generation	Parameter controlling shape of the technology learning function. Dimension: technology.	Input from file KGENTK	Unitless
bldgshr	B-148	Distributed Generation	Percentage used to distribute exogenous penetrations across building types. Dimension: technology, building type	Input from file KGENTK	Percentage
btuwasteheat	B-137	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-125	Distributed Generation	“First of a kind” capital cost for a distributed generation technology.	Input from KGENTK	1999 Dollars

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation</b>				
capcost	B-129	Distributed Generation	Capital cost of equipment per kw. Dimensions: technology and vintage. May be adjusted based on technology learning.	Input from file KGENTK, Calculated	1999 dollars/kw
cumnetcashflow	--	Distributed Generation	Accumulated sum of all prior netcashflow amounts.	Computed	Nominal Dollars
degred	B-135	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	
depr	B-129	Distributed Generation	Computed straight line depreciation amount = installed cost divided by tax life (taxlife). Dimension: year.	Computed	Nominal Dollars
downpay	B-126	Distributed Generation	The down payment percentage times the total installed cost for the specific technology and vintage being analyzed	Computed	1999 Dollars
downpaypct	--	Distributed Generation	Down payment percentage assumed to apply to loans for distributed generation investment	Input from file KGENTK	Percentage
elecavgkwh	B-142	Distributed Generation	Average annual electricity usage in kWh from CBECS estimated for a building with floorspace 4 times greater than average. Dimension: building type.	Input in FORTRAN Data Statement	KWh per year
eleff	B-132	Distributed Generation	Electrical conversion efficiency. Dimensions: technology and vintage.	Input from file KGENTK	Percentage

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation</b>				
eqlife	--	Distributed Generation	Useful life of equipment. Dimensions: technology and vintage.	Input from file KGENTK	Years
equipmentcost	B-125	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	1999 Dollars
equipname	--	Distributed Generation	Name for reporting purposes. Dimensions: technology.	Input from file KGENTK	Character data
excesskwh	B-142	Distributed Generation	KWh generated in excess of estimated requirements for the building that will be sold to the electric utility (grid sales).	Computed	KWh
exogpen	B-148	Distributed Generation	Program-driven cumulative units. Dimensions: Census division, technology, year.	Input from file KGENTK	Number of units
fuelcost	B-141	Distributed Generation	Fuel cost for the technology net of any water heating cost savings from using waste heat Dimension: year.	Computed	Nominal Dollars
fuelinput	B-136	Distributed Generation	MMBtu of fuel input by the technology.	Computed	MMBtu
fuelusage	B-97	Distributed Generation	Accumulated total fuel consumption (if applicable) for all distributed generators. Dimension: year, Census division, technology, fuel.	Computed	Trillions of Btu
hwbtu	B-96	Distributed Generation	Accumulated total water heating Btus provided by distributed resources. Dimension: year, Census division, technology	Computed	Trillions of Btu

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation</b>				
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-141	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-129	Distributed Generation	Installation cost per kw. Dimensions: technology and vintage.	Input from file KGENTK	1999 dollars/kw
intamt	B-131	Distributed Generation	Interest paid for the loan in each year of the analysis – determines the tax deduction that can be taken for interest paid.	Computed	Nominal Dollars
intRate	B-126	Distributed Generation	Commercial mortgage rate	Input from file KGENTK	Percentage
invest	B-149	Distributed Generation	Current year investment in distributed resources. Dimension: year, Census division, technology.	Computed	Millions of 1998 Dollars
kw	B-129	Distributed Generation	System peak capacity. Dimensions: technology and vintage.	Input from file KGENTK	KW

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
kwh	B-135	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-128	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-132	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-144	Distributed Generation	The maintenance cost from the input file for the specific technology and vintage being analyzed and inflated to current year dollars for the cashflow analysis. Dimension: year.	Computed	Nominal Dollars
maxpen	B-146	Distributed Generation	Computed maximum penetration into new construction.	Computed	Percentage
modulesqft	B-133	Distributed Generation	Estimated PV array square footage for a 1-kw system.	Computed	Square Feet
netcashflow	B-145	Distributed Generation	Dimension: year.	Computed	Nominal Dollars
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 is now provided by the NEMS Electric Market Module. Dimensions: technology and Census division.	Input from file KGENTK	Percentage

**Table A-1. NEMS Commercial Module Inputs and Outputs**

<b>Input/Output Name</b>	<b>Equation</b>				
operhours	B-134	Distributed Generation	Operation hours. Dimensions: technology and vintage.	Input from file KGENTK	Hours
payment	B-126	Distributed Generation	Computed annual payment using loan amortization formula	Calculated	1999 Dollars
pen	B-147	Distributed Generation	Computed penetration into new construction.	Computed	Percentage
penparm	B-146	Distributed Generation	Parameter controlling maximum penetration into new construction. Dimension: technology.	Input from file KGENTK	Unitless
prin	B-127	Distributed Generation	The amount 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-96	Distributed Generation	Accumulated total space heating Btus provided by distributed resources. Dimension: year, Census division, technology	Computed	Trillions of Btu
simplepayback	B-147	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
solarins	B-132	Distributed Generation	Solar insolation for photovoltaics. Dimensions: technology and vintage.	Input from file KGENTK	kWh per square foot per year
spacehtgmmmbtu	B-139	Distributed Generation	If available Btu of waste heat is greater than water heating requirements, then any additional available heat is used to serve space heating.	Computed	MMBtu per year

**Table A-1. NEMS Commercial Module Inputs and Outputs**

Input/Output Name	Equation				
taxcredit	B-130	Distributed Generation	Computed tax credit computed as the maximum of taxcreditmax and the taxcreditpct times the total installed cost. Dimension: year.	Computed	Nominal Dollars
taxdeduct	B-131	Distributed Generation	Combined tax rate times interest paid in the previous year plus any applicable tax credit. Dimension: year.	Computed	Nominal Dollars
term	B-126	Distributed Generation	Commercial loan term	Input from file KGENTK	Years
trills	B-94	Distributed Generation	Accumulated total electric generation by all distributed generators. Dimension: year, Census division, technology	Computed	Trillions of Btu
trillsownuse	--	Distributed Generation	Accumulated total electric generation retained for own use on-site. Dimension: year, Census division, technology.	Computed	Trillions of Btu
txcreditmax	B-130	Distributed Generation	cap on the total dollar amount of a tax credit (if any) Dimensions: technology and vintage.	Input from file KGENTK	1999 dollars
txcreditpct	B-130	Distributed Generation	Percentage applied to installed cost for computing tax credit.	Input from file KGENTK	Percentage
txlife	B-129	Distributed Generation	Tax life of equipment, generally different from useful life. Dimensions: technology and vintage.	Input from file KGENTK	Years
units	B-148	Distributed Generation	Total number of units with distributed generation installed. Dimension: year, Census division, technology	Computed	Number of Units

<b>Input/Output Name</b>	<b>Equation Number</b>	<b>Subroutine</b>	<b>Definition and Dimensions</b>	<b>Classification</b>	<b>Units</b>
valesave	B-143	Distributed Generation	Inflated base year value of energy savings in nominal dollars for the cashflow analysis. Dimension: year.	Computed	Nominal Dollars
valesavebase	B-143	Distributed Generation	Initial value of generated electricity savings to begin the casflow model net benefits calculation.	Computed	1999 Dollars
waterhtgmmbtu	B-138	Distributed Generation	The lesser of: 1) average annual water heating EUI from CBECS (estimated for a building with 4 times greater than average floorspace), and 2) the available Btu of waste heat estimated from the distributed generation technology. Dimension: building type.	Computed	MMBtu per year
whrecovery	B-137	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 heating which provides additional energy cost savings for distributed generation technologies. Dimensions: technology and vintage.	Input from file KGENTK	Percentage

<b>MODEL INPUT:</b>	Proportion of base year office equipment EUI attributable to PC use
<b>VARIABLE NAME:</b>	BaseYrPCShrofOffEqEUI
<b>MODEL COMPONENT:</b>	Service Demand
<b>DEFINITION:</b>	PCS proportion of base year office equipment EUI
<b>CLASSIFICATION:</b>	Input parameter (KPARM)

**DISCUSSION:**

The 1995 Commercial Buildings Energy Consumption Survey (CBECS 95) provides data on energy consumption by building, and includes data on the number of PCS present in each building surveyed. CBECS 95 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 1995 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/](http://www.eia.doe.gov/emeu/cbecs/).

<b><u>MODEL INPUT:</u></b>	Consumer behavior rule proportions
<b><u>VARIABLE NAME:</u></b>	BehaviorShare
<b><u>MODEL COMPONENT:</u></b>	Technology Choice
<b><u>DEFINITION:</u></b>	Proportions of commercial consumers using the least cost, same fuel, and same technology behavior rules for decision type <i>d</i> in building type <i>b</i>
<b><u>CLASSIFICATION:</u></b>	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* are utilized to weight these estimates by building type to yield replacement and retrofit behavior rule proportions by building type. 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: Characteristics, Energy Consumption, and Energy Expenditures*. Washington DC, October 1998, DOE/EIA-0625(95), GPO Stock No. 061-003-01046-6

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.

<b><u>MODEL INPUT:</u></b>	Base year commercial floorspace
<b><u>VARIABLE NAME:</u></b>	CBECStSp
<b><u>MODEL COMPONENT:</u></b>	Floorspace
<b><u>DEFINITION:</u></b>	Commercial floorspace by building type <i>b</i> in Census division <i>r</i> for 1995
<b><u>CLASSIFICATION:</u></b>	Input from file KFLSPC

**DISCUSSION:**

A straightforward aggregation of weighted survey data from CBECS 95 was used to compute 1995 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:**

<u>NEMS</u>	<u>CBECS 95</u>
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 and Service
Warehouse	Refrigerated Warehouse Non-refrigerated Warehouse
Other	Laboratory Public Order and Safety Parking Garage Vacant Other

**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/](http://www.eia.doe.gov/emeu/cbecs/).

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.

<b><u>MODEL INPUT:</u></b>	Expected building lifetimes
<b><u>VARIABLE NAME:</u></b>	CMAvgAge
<b><u>MODEL COMPONENT:</u></b>	Floorspace
<b><u>DEFINITION:</u></b>	Median building lifetime by building type <i>b</i>
<b><u>CLASSIFICATION:</u></b>	Input from file KBLDG

**DISCUSSION:**

The sources cited below provided various estimates of average building lifetimes for the building types considered by the NEMS Commercial Sector Demand Module. Where estimates differed between the sources, a simple average value was used. In some cases, NEMS analysts' judgement provided building lifetimes that overrode the published values because of differing interpretations of the concept of "useful" lifetimes, and the need to insure that the particular building survival function used performed in accordance with historical data. 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 following sources:

**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.

**MODEL INPUT:** Cogeneration of electricity by commercial sector facilities  
**VARIABLE NAME:** CMCogenEI  
**MODEL COMPONENT:** End-Use Consumption  
**DEFINITION:** Commercial sector cogeneration forecast by fuel *f* to meet service demand *s* in  
Census division *r*  
**CLASSIFICATION:** Calculated variable after 1996; Input from file KCOGEN prior to 1997

**DISCUSSION:**

Historical data for commercial sector SIC codes from the EI-860: Annual Electric Generator Report - Nonutility for the year 1996 forms the basis for the forecast of cogenerated power by fuel and Census division. The EI-860B 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 data base 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 forecast years after 1996, the baseline forecast of cogeneration by source fuel is set at the prior year's level per square foot of floorspace, with a price sensitivity component that uses the percent changes from the prior year electricity prices and generating fuel prices.

**SOURCES:**

Energy Information Administration. Form EI-860B: Annual Electric Generator Report - Nonutility.  
Energy Information Administration, "Nonutility Power Producers," *Electric Power Monthly*, April 1995.

<b><u>MODEL INPUT:</u></b>	Floorspace survival function shape parameter
<b><u>VARIABLE NAME:</u></b>	CMGamma
<b><u>MODEL COMPONENT:</u></b>	Floorspace
<b><u>DEFINITION:</u></b>	Shape parameter for the floorspace survival function
<b><u>CLASSIFICATION:</u></b>	Input parameter from file KBLDG

**DISCUSSION:**

The sources cited below provide data on average building lifetimes, together with expected surviving proportions after various periods of time. The NEMS Commercial Sector Demand Module models floorspace retirement using the logistic survival function,

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

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 calculated so that the documented percentage of buildings remaining one year after construction is obtained.

**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.

**MODEL INPUT:** Oldest modeled buildings  
**VARIABLE NAME:** CMOldestBldgVint  
**MODEL COMPONENT:** Floorspace  
**DEFINITION:** Median year of construction for buildings in the earliest CBECS age cohort group  
**CLASSIFICATION:** Input parameter

**DISCUSSION:**

CBECS 95 building characteristics include the year of building construction. Eight 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. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site [www.eia.doe.gov/emeu/cbecs/](http://www.eia.doe.gov/emeu/cbecs/).

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

<b><u>MODEL INPUT:</u></b>	Historical fuel consumption
<b><u>VARIABLE NAME:</u></b>	CMSEDS
<b><u>MODEL COMPONENT:</u></b>	Consumption
<b><u>DEFINITION:</u></b>	State Energy Data System (SEDS) historical energy consumption by Census division, fuel, and year for the commercial sector
<b><u>CLASSIFICATION:</u></b>	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 forecasts are benchmarked during the historical portion of the forecast horizon. 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 1997. This data is supplemented with projections from the Short Term Energy Outlook (STEO) for the commercial sector for the years 1998 - 2001. STEO data for 1998 and 1999 are treated by the Commercial Module as if it were SEDS data, which is very likely to become the actual case. STEO data for 2000 and 2001 is available for optional benchmarking during those years, at the user's discretion. For AEO2001, the NEMS Commercial Module benchmarks to STEO data through the year 2000.

**SOURCES:**

Energy Information Administration. *State Energy Data Report 1997 Consumption Estimates*. DOE/EIA-0214(97). September 1999.

**MODEL INPUT:** Floorspace vintages  
**VARIABLE NAME:** CMVintage  
**MODEL COMPONENT:** Floorspace  
**DEFINITION:** Median year of construction of commercial floorspace existing in 1995, by building type, Census division, and vintage cohort group.  
**CLASSIFICATION:** Input from file KVINT

**DISCUSSION:**

The CBECs 1995 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 - 1992
- 1993 - 1995

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. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site [www.eia.doe.gov/emeu/cbecs/](http://www.eia.doe.gov/emeu/cbecs/).

**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<sup>2</sup>.  
**CLASSIFICATION:** Input from file KINTENS

**DISCUSSION:**

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. The resulting EUI estimates are subjected to a smoothing procedure and then input to the Commercial Module from the KINTENS input file.

**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/](http://www.eia.doe.gov/emeu/cbecs/).

Original work by Eugene Burns of the U.S. Department of Energy, 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*. Data is available from 1990 through the last STEO forecast year, currently 2000. Data for the final year (2001) provides the average heating and cooling degree days for normal years. The data is used to perform a weather adjustment to the consumption forecast in the Consumption subroutine to account for historical and 'normal' differences from the base year (1995) 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/](http://nic.fb4.noaa.gov/products/analysis_monitoring/cdus/).

**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 CBECS 1995 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.

**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/](http://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:**

The estimated efficiency improvement factors for office equipment, subdivided into personal computers (PC) and non personal-computer (NonPC) categories, and miscellaneous or “other” services are developed from the EPRI and LBL sources cited below. The annual improvement factor required to reach the estimated level of efficiency in the year 2020 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 2020.

**SOURCES:**

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

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. 5-48 to 5-84, 6-33, 6-40.

Arthur D. Little, Inc., *Technical Memorandum for Technology Advances and Forecasts - Residential/Commercial End-Use Equipment*, ADL reference 64460-09, prepared for U.S. Department of Energy, Contract No. DE-AC-21-88, April 1990, pp. 4-3, 8-4, 8-5, 10-5.

Gas Research Institute, *Baseline Projection Data Book: GRI Baseline Projection of U.S. Energy Supply and Demand to 2010*, 1992 edition, Vol. I, pp. 156-158.

Geller, Howard S., *Commercial Building Equipment Efficiency: A State-of-the-Art Review*, report prepared for the U.S. Congress, Office of Technology Assessment, Energy & Materials Program by The American Council for an Energy-Efficient Economy, Washington, DC, May 1988.

Mahoney, Daniel D., *Phase I of a Project to Enhance the Commercial Section Analysis of the GRI Baseline Modeling System; Topical Report #1: Data Enhancements*, prepared for the Gas Research Institute under Contract No. 5085-800-1175, DRI Energy Division, Lexington, MA, July 1987, pp.4, 59, 139-140.

U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518, Washington, DC, U.S. Government Printing Office February 1991, p.122.

U.S. Department of Energy, Energy Information Administration, *Lighting in Commercial Buildings*, EIA, Washington, DC, March 1992, p. 41.

U.S. Department of Energy, Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, EIA, Washington, DC, December 1990, p.52.

U.S. Department of Energy, Energy Information Administration, *PC-AEO Forecasting Model for the Annual Energy Outlook: Model Documentation*, EIA, Washington, DC, March 1990, p.III-37 to III-39.

**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 (1995) 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 KPARAM

**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 (1995) 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 Lawrence Berkeley Laboratory sources cited below documents the LBL studies performed to forecast office equipment market penetration. The principal source of commercial base year PC stock data is CBECs 1995. Data on energy consumption (both Energy Star and other) of PCs, monitors and laser printers are from *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, prepared for EIA by ADL, and LBL's *Efficiency Improvements in U.S. Office Equipment* report. The LBL report also provides estimates of sales for PC-related office equipment. Estimates of the enabling rate for Energy Star PCS is derived from an EPA communication. The market penetration index is set to unity in 1995, and the forecast from LBL's *Energy Use and Trends* report is indexed to the 1995 base year. The indexed LBL forecast of office equipment market penetration is included in the NEMS Commercial Module calculation of service demand.

**SOURCES:**

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

Arthur D. Little, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, ADL reference 37125, prepared for U.S. Department of Energy, Contract No. AC01-96CE23798, September 1998.

Piette, M., J. Eto, and J. Harris, *Office Equipment Energy Use and Trends*, Energy and Environment Division, Lawrence Berkeley Laboratory, September 1991.

U.S. Environmental Protection Agency, personal communication (facsimile) regarding Energy Star program. June 12, 1995.

<b><u>MODEL INPUT:</u></b>	Minor fuel consumption elasticity parameters
<b><u>VARIABLE NAMES:</u></b>	MinFuelAlpha, MinFuelBeta
<b><u>MODEL COMPONENT:</u></b>	Consumption
<b><u>DEFINITION:</u></b>	Elasticity parameters used in the calculation of minor fuel consumption
<b><u>CLASSIFICATION:</u></b>	Input from file KMINFL

**DISCUSSION:**

MinFuelAlpha and MinFuelBeta are used as follows:

$$\begin{aligned}
 FinalEndUseCon_{f,b,r,y} = & \left( e^{MinFuelAlpha_{r,f}-CMnumMajFl} \right. \\
 & \times Price_{f,r,y}^{MinFuelBeta_{r,f}-CMnumMajFl} \\
 & \times 10^{-6} \\
 & \left. \times (SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}) \right) \\
 \forall f \in \{MinFuels\} - \{MotorGasoline\}, b, r, y
 \end{aligned}$$

where FinalEndUseCon is final end-use minor fuel consumption. Minor fuel final end-use consumption is measured in trillion Btu in for  $f \in \{\text{residual fuel oil, LPG, coal, kerosene}\}$  for Census division  $r$  for year  $y$ , and is calculated for all forecast years by the expression above. For motor gasoline, consumption levels are set to the published SEDS historical values by Census division for the historical portion of the forecast horizon, and subsequently are developed by multiplying the previous year's motor gasoline consumption by the term,  $(1 + \text{MinFuelBeta})$ , which is based upon SEDS historical share growth for motor gasoline consumption. MinFuelBeta and MinFuelAlpha are 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:** 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.

<b><u>MODEL INPUT:</u></b>	Serviced floorspace variation with building vintage
<b><u>VARIABLE NAME:</u></b>	ServicedFlspcProp
<b><u>MODEL COMPONENT:</u></b>	Service Demand
<b><u>DEFINITION:</u></b>	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).
<b><u>CLASSIFICATION:</u></b>	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 is 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.

<b><u>MODEL INPUT:</u></b>	Building shell efficiency index
<b><u>VARIABLE NAME:</u></b>	ShellEffIndex
<b><u>MODEL COMPONENT:</u></b>	Service Demand
<b><u>DEFINITION:</u></b>	Shell efficiency index for buildings constructed in the current year for building type <i>b</i> in Census division <i>r</i> in year <i>y</i> .
<b><u>CLASSIFICATION:</u></b>	Input from file KSHEFF

**DISCUSSION:**

The 1995 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 LBL 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 1989, 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 1995 CBECS was used to adjust the indices for new construction between 1990 and 1995.

**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. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site [www.eia.doe.gov/emeu/cbecs/](http://www.eia.doe.gov/emeu/cbecs/).

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:**

The following table 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 selected from within the range illustrated in this table, to correspond to analyst judgement within the range of empirical values developed.

**Table A-2. Price Elasticity Literature Review**

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 forecast  
**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:**

A baseline projection for solar thermal energy consumption developed by the National Renewable Energy Laboratory (NREL) is read into the Commercial Module, since forecasts from the NEMS Renewable Fuels Module are not currently available at the level of disaggregation required by the Commercial Module. The renewable energy forecasts for active solar (space heating and water 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-860B: Annual Electric Generator Report - Nonutility data base.

**SOURCES:**

Energy Information Administration, EI-860B: Annual Electric Generator Report - Nonutility 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 EPRI, ADL, GRI, OTA, NES, AEO90, and *Lighting in Commercial Buildings* sources cited below.

**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.

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

Arthur D. Little, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, ADL reference 37125, prepared for U.S. Department of Energy, Contract No. AC01-96CE23798, September 1998.

Arthur D. Little, Inc., *Energy Savings Potential for Commercial Refrigeration Equipment*, ADL reference 46230, prepared for U.S. Department of Energy, Contract No. AC01-89CE23821, June 1996.

Lawrence Berkeley Laboratory, Energy and Environment Division, Energy Analysis Program, *Technology Data Characterizing Lighting in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0*, September 1993.

Pietsch, J., *TAG Technical Assessment Guide, Vol. 2: Electricity End Use: Part 2: Commercial Electricity Use -- 1992*, Dallas, TX, Electric Power Research Institute, December 1992.

U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518, Washington DC, U.S. Government Printing Office, May 1992, pp. 51-55.

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, p. 122.

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.

Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, SR/NES/90-02, Washington DC, December 1990, p. 52.

<b><u>MODEL INPUT:</u></b>	Base year equipment market share
<b><u>VARIABLE NAME:</u></b>	TechShareofServiceBASE
<b><u>MODEL COMPONENT:</u></b>	Technology Choice
<b><u>DEFINITION:</u></b>	Current year market share of technology <i>k</i> of vintage <i>v</i> that meets service demand <i>s</i> in building type <i>b</i> in Census division <i>r</i> .
<b><u>CLASSIFICATION:</u></b>	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 CBECS 1995. 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. 1995 Commercial Buildings Energy Consumption Survey, Public Use Data. Washington DC, February 1998, web site [www.eia.doe.gov/emeu/cbecs/](http://www.eia.doe.gov/emeu/cbecs/).

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.

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

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.

Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, EIA, Washington, DC, December 1990.

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

Arthur D. Little, Inc., *Energy Savings Potential for Commercial Refrigeration Equipment*, ADL reference 46230, prepared for U.S. Department of Energy, Contract No. AC01-89CE23821, June 1996.

<b><u>VARIABLE NAME:</u></b>	TimePrefPrem
<b><u>MODEL INPUT:</u></b>	Consumer time preference distribution data
<b><u>MODEL COMPONENT:</u></b>	Technology Choice
<b><u>DEFINITION:</u></b>	The consumer 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 time preference interest rate premium segment.
<b><u>CLASSIFICATION:</u></b>	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 (LBL), DAC/SAIC, four electric utility studies, and an EIA market study. Three of the distributions were performed for specific technologies, and two are generalized to represent 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 time preferences as functions of technology characteristics, an average distribution across all technologies is applied.

The average consumer 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.<sup>1</sup> 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 time preference premium distribution for each source.<sup>2</sup> 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.<sup>3</sup> Finally, the

---

<sup>1</sup>The conversion to implied internal rates of return assumed mid-year payments and a thirty year amortization period.

<sup>2</sup>The Treasury bond rates were obtained from the Statistical Abstract and from personal communication with EIA's Macro and Financial Information Branch staff.

<sup>3</sup>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.

resulting average distribution is aggregated to yield a distribution of six time preference segments.

The assumed distribution of consumer time preference premiums is assumed constant over the forecast horizon. 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.

**VARIABLE NAMES:** TechCost, TechLife  
**MODEL INPUT:** Equipment characteristics (see Definition below)  
**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:**

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. 5-48 to 5-84, 6-33, 6-40.

Arthur D. Little, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, ADL reference 37125, prepared for U.S. Department of Energy, Contract No. AC01-96CE23798, September 1998.

Arthur D. Little, Inc., *Energy Savings Potential for Commercial Refrigeration Equipment*, ADL reference 46230, prepared for U.S. Department of Energy, Contract No. AC01-89CE23821, June 1996.

Chaing, J.H., ed., *Means Electrical Cost Data, 17th Annual Edition*. R.S. Means Company, Inc., Kingston, MA, 1994.

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.

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

Gas Research Institute, *Baseline Projection Data Book: GRI Baseline Projection of U.S. Energy Supply and Demand to 2010*, 1992 edition, Vol. I, pp. 156-158.

Lawrence Berkeley Laboratory, Energy and Environment Division, Energy Analysis Program, *Technology Data Characterizing Lighting in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0*, September 1993.

Means Southern Construction Information Network, *Means Facilities Construction Cost Data*, 1995.

Means Southern Construction Information Network, *Means Facilities Maintenance and Repair Cost Data*, 1995.

Pietsch, J., *TAG Technical Assessment Guide, Vol. 2: Electricity End Use: Part 2: Commercial Electricity Use -- 1992*, Dallas, TX, Electric Power Research Institute, December 1992.

U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518, Washington, DC, U.S. Government Printing Office February 1991,p.122.

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.

Energy Information Administration, *Lighting in Commercial Buildings*, DOE/EIA-0555(92)/1, Washington, DC, March 1992, p. 41.

Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, SR/NES/90-02, Washington, DC, December 1990, p.52.

U.S. Department of Energy, Energy Information Administration, *PC-AEO Forecasting Model for the Annual Energy Outlook: Model Documentation*, DOE/EIA, Washington, DC, March 1990, p.III-37 to III-39.

Geller, Howard S., *Commercial Building Equipment Efficiency: A State-of-the-Art Review*, report prepared for the U.S. Congress, Office of Technology Assessment, Energy & Materials Program by The American Council for an Energy-Efficient Economy, Washington, DC, May 1988.

**VARIABLE NAME:** TechAvailability  
**MODEL INPUT:** Equipment Availability  
**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 EPRI, ADL, GRI, OTA and EIA 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:**

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. 5-48 to 5-84, 6-33, 6-40, 7-16, 7-19.

Arthur D. Little, Inc., *EIA - Technology Forecast Updates - Residential and Commercial Building Technologies*, ADL reference 37125, prepared for U.S. Department of Energy, Contract No. AC01-96CE23798, September 1998.

Arthur D. Little, Inc., *Energy Savings Potential for Commercial Refrigeration Equipment*, ADL reference 46230, prepared for U.S. Department of Energy, Contract No. AC01-89CE23821, June 1996.

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.

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

Gas Research Institute, *Baseline Projection Data Book: GRI Baseline Projection of U.S. Energy Supply and Demand to 2010*, 1992 edition, Vol. I, pp. 156-158.

Lawrence Berkeley Laboratory, Energy and Environment Division, Energy Analysis Program, *Technology Data Characterizing Lighting in Commercial Buildings: Application to End-Use Forecasting with COMMEND 4.0*, September 1993.

Pietsch, J. *TAG Technical Assessment Guide, Vol. 2: Electricity End Use; Part 2: Commercial Electricity Use -- 1992*, Dallas, TX, Electric Power Research Institute, December 1992.

U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518, Washington DC, U.S. Government Printing Office, May 1992, pp. 51-55.

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, p. 122.

Energy Information Administration, *Lighting in Commercial Buildings*, DOE/EIA-0555(92)/1, Washington DC, March 1992, p. 41.

Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, SR/NES/90-02, Washington DC, December 1990, p. 52.

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

**MODEL INPUT:** Distributed Generation Equipment Characteristics

**VARIABLE NAMES:** degred, eleff, eqlife, taxlife, instcost, capcost,  
maintcst, avail, whrecovery, txcrpct, txcrmax, kw,  
lossfac, netmeteradj, operhours, solarins, ifirstyr,  
ilastyr, ifueltype, equipname

**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 commercial tax credit for photovoltaics of up to 10% of the installed cost with a maximum in any one year of \$25,000.

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.

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

**CLASSIFICATIONS:** Input from file KGENTK

**DISCUSSION:**

degred (technology, vintage) – 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.

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 39.5 years)

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 1999 dollars per kw.

capcost (technology, vintage) – capital cost of the investment in 1999 dollars per kw.

maintcst (technology, vintage) – annual maintenance cost in 1999 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 (the technologies don't overlap and are generally updated in the menu at five-year intervals)

ifueltype (technology) – fuel type pointer for generation technologies other than photovoltaics, currently this is 3 for natural gas which is used by fuel cells

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

#### **SOURCES:**

System Capacities and Operating Hours are Energy Information Administration assumptions.

Solar Insolation - NREL communication to US DOE EE.

Solar Photovoltaic Technology Specifications - DOE/EPRI, TR-109496, Dec. 1997.

Technologies other than Solar Photovoltaic- ONSITE SYCOM Energy Corporation, *The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector*, prepared for U.S. Department of Energy - Energy Information Administration, January 2000.

**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).

**CLASSIFICATIONS:** Input from file KGENTK

**DISCUSSION:**

term – loan term currently set at 20 years

intrate – commercial mortgage rate from the kgentk input file, currently set to 8%.

downpaypct – down payment percentage assumed to apply to the distributed generation investment, currently 20% 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.

**SOURCE:**

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.

**CLASSIFICATIONS:** Input from file KGENTK

**DISCUSSION:**

**SOURCE:**

Exogenous penetrations: Database from DOE PV program, DOE News releases, UPVG website, and Million Solar Roofs website.

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

**MODEL INPUT:** Distributed Generation Building-Specific Energy  
Use  
Characteristics

**VARIABLE NAMES:** elecavgkwh, waterhtgmmbtu, spacehtgmmbtu

**MODEL COMPONENT:** CDistGen

**DEFINITION:**

Average electricity usage, average annual waterheating energy consumption, average annual space heating energy consumption.

**CLASSIFICATIONS:** 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

**SOURCE:**

US 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.

**MODEL INPUT:** Distributed Generation Penetration Function  
Parameters

**VARIABLE NAMES:** alpha, penparm

**MODEL COMPONENT:** CDistGen

**DEFINITION:**  
Technology-specific penetration function parameters.

**CLASSIFICATIONS:** Input from file KGENTK

**DISCUSSION:**

**SOURCE:**  
Energy Information Administration. Assumptions.

[This page intentionally left blank]

## Appendix B. Mathematical Description

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 Cogeneration Submodule are found at the end of Appendix B. Certain conventions, nomenclature, and symbols used in the equations are defined below.

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

<u>Subscript</u>	<u>Description of Dimension Represented by Subscript</u>
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 or model of floorspace or equipment, depending on usage
p	Consumer time preference premium segment
y	Year designation (unless otherwise indicated, year ranges from 1996 through 2020, with the year 1996 indexed to the value 7 in the FORTRAN code. The equations below treat y as the calendar year.)
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:

<u>Symbol</u>	<u>Meaning</u>
$\forall$	for all
$\in$	belonging to the category of
$\ni$	such that
$\exists$	there exists
$\bullet$ or $\times$	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<sub>t,f</sub> = 1 if technology t uses fuel f, and is 0 otherwise.

TechbyService<sub>s,t</sub> = 1 if technology t provides service s, and is 0 otherwise.

Most formulae are evaluated only for the current year of the forecasts. 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:**

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

$y_0 \equiv$  year of construction

**Backcast 1995 existing floorspace to new construction in original year of construction:**

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

$y' \equiv$  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 1899; 2) 1900-1919; 3) 1920-1945; 4) 1946-1959; 5) 1960-1969; 6) 1970-1979; 7) 1980-1989; 8) 1990-1992; and 9) 1993-1995. In this case,  $y'$  ranges from 1825 through 1995.

**Previously-constructed floorspace surviving into the current year:**

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

**First estimate of new floorspace construction:**

$$\begin{aligned} \tilde{CMNewFloorSpace}_{r,b,y} = & CMTotalFlsp_{r,b,CBECSyear} \cdot \frac{\sum_{b'} [DRItCBECs_{b,b'} \cdot MC\_COMMFLSP_{r,b',y}]}{\sum_{b'} [DRItCBECs_{b,b'} \cdot MC\_COMMFLSP_{r,b',CBECSyear}]} \\ & - SurvFloorTotal_{r,b,y} \end{aligned} \quad (\text{B - 4})$$

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

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

**First estimate of total commercial floorspace:**

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

$$CMTotalFlspc_{r,b,y}^{\sim} = SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}^{\sim} \quad (B - 6)$$

$$CDRatio_r = \left( \frac{MC\_COMMFLSP_{r,1,y}}{MC\_COMMFLSP_{r,1,CBECsYear}} \right) \div \left( \frac{\sum_b CMTotalFlspc_{r,b,y}^{\sim}}{\sum_b CMTotalFlspc_{r,b,CBECsYear}} \right) \quad (B - 7)$$

Where the value of 1 for the middle subscript of MC\_COMMFLSP denotes the Census division total commercial floorspace, across all NEMS MAM (DRI) building types.

**Revised forecast of new commercial floorspace construction and total floorspace:**

$$CMNewFloorSpace_{r,b,y} = CMTotalFlspc_{r,b,CBECsYear} \cdot \frac{\sum_{b'} [DRItoCBECs_{b,b'} \cdot MC\_COMMFLSP_{r,b',y}]}{\sum_{b'} [DRItoCBECs_{b,b'} \cdot MC\_COMMFLSP_{r,b',CBECsYear}]} \cdot CDRatio_r - SurvFloorTotal_{r,b,y} \quad (B - 8)$$

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

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

## Service Demand Equations

**Total Energy Use Intensities:**

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

$$F \equiv \text{"total across major fuels"} = CMnumMajFl + 1$$

**Split Office Equipment EUI into PC and Non-PC if not specified separately:**

*If BaseYrPCShrofOffEqEUI ≥ 0 Then*

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

$$ComEUI_{r,b,s=PCOffEq,f} = ComEUI_{r,b,s=PCOffEq,f} \cdot BaseYrPCShrofOffEqEUI \quad (B - 12)$$

*f ∈ {MajorFuels}*

*otherwise, unchanged*

**Total consumption by end-use in 1995:**

$$CforStotal_{[r,s]} = \sum_b [ComEUI_{r,b,s,F} \cdot CMTotalFlspc_{r,b,CBECYear}] \quad (B - 13)$$

**End-use fuel consumption in 1995 in buildings to which particular equipment is restricted:**

$$CforSrestrict_{[t,v,r,s]} = \sum_b [ComEUI_{r,b,s,F} \cdot CMTotalFlspc_{r,b,CBECYear} \cdot (1 - EquipRestriction_{t,v,b,r})] \quad (B - 14)$$

*Techavailability<sub>t,v,1</sub> ≤ CBECYear*

Revise initial equipment market shares to reflect building restrictions:

$$\begin{aligned}
 TechShareofServiceBASE_{r,b,s,t,v} &= TechShareofServiceBASE_{r,b,s,t,v} \cdot \frac{CforStotal}{CforSrestrict}, \text{ if } EquipRestriction_{t,v,b,r} = 0 \\
 &0, \text{ otherwise}
 \end{aligned} \tag{B - 15}$$

$$TechAvailability_{t,v,1} \leq CBECSyear$$

$$\begin{aligned}
 TechShareofService_{r,b,s,t,v} &= \frac{TechShareofServiceBASE_{r,b,s,t,v}}{\sum_{b'} \sum_{t',v'} TechShareofServiceBASE_{r,b',s,t',v'}} \\
 TechAvailability_{t',v',1} &\leq CBECSyear \\
 TechAvailability_{t,v,1} &\leq CBECSyear
 \end{aligned} \tag{B - 16}$$

Here, b' is used as an alternative NEMS Commercial Module building type index rather than as a NEMS MAM (DRI) 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 1995 by fuel, end-use, building type, and Census division:

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

Apply fuel-specific factor to bring 1995 equipment market shares and EUI's into agreement:

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

$$TechShareofServiceBASE_{r,b,s,t,v} = TechShareofServiceBASE_{r,b,s,t,v} \cdot KScale_f \quad (\text{B - 19})$$

$f \in \{Major\ Fuels\}; \forall t,v \ni FuelbyTech_{t,f} = 1$

Service Demand Intensities (SDI) prevailing in 1995:

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

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

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

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

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

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

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

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

$$ExistShBaseStock_{s,b,r,y} = \left( \text{Maximum}(ExistImprov, ShellEffIndex_{b,r,2})^{\frac{1}{(2020-CBECYear)}} \right)^{(y-CBECYear)} \quad (\text{B - 23})$$

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

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

$$ShellEffIndex_{b,r,1} = ExistShBaseStock_{s,b,r,y} \cdot (SurvFloorTotal_{r,b,y} - TotNewFS) + \sum_{y=CMFirstYr}^{y-1} \left[ CMNewFloorspace_{r,b,y} \cdot ShellEffIndex_{b,r,2} \cdot \left( NewImprv^{\frac{1}{(2020-CBECYear)}} \right)^{(y-CBECYear)} \right] \quad (\text{B - 24})$$

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

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

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot ShellEffIndex_{b,r,1} \quad (\text{B - 25})$$

$s \in \{SpHeat\}$

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot \left[ (ShellEffIndex_{b,r,1} - 1.0) \cdot (-0.1) + 1.002 \right] \quad (\text{B - 26})$$

$s \in \{SpCool\}$

Basic forecast of service demands in new floorspace construction:

$$NewServDmd_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \times 10^{-3} \cdot CMNewFloorspace_{r,b,y} \quad (\text{B - 27})$$

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

Calculate the current year improvement to new heating shell efficiency:

$$NewShAdj = \left( NewImprv \frac{1}{(2020-CBECsYear)} \right)^{(y-CBECsYear)} \quad (\text{B - 28})$$

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

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

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

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

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

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

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

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot \frac{ServicedFlspcProp_{b,s,new}}{ServicedFlspcProp_{b,s,existing}} \quad (\text{B - 31})$$

$$s \leq CMnumVarSDI$$

Minor service demand forecast with 1995 average efficiency indexed to one:

$$ServDmdExBldg_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \times 10^{-3} \cdot SurvFloorTotal_{r,b,y} \quad (\text{B - 32})$$

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

$$NewServDmd_{s,b,r,y} = ServDmdIntenBASE_{s,b,r} \times 10^{-3} \cdot CMNewFloorspace_{r,b,y} \quad (\text{B - 33})$$

$$s \in \{ Minor Services \}$$

Effect of continuing market penetration on demands for certain services:

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot MarketPenetration_{s,y} \quad (\text{B - 34})$$

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

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \cdot MarketPenetration_{s,y} \quad (\text{B - 35})$$

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

Reduce demands by amounts satisfied using solar energy directly:

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - \left( \frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} \cdot \frac{SurvFloorTotal_{r,b,y}}{TotalFloorspace_{r,b,y}} \right) \quad (\text{B - 36})$$

$s \in \{ Solar Services \}$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} - \left( \frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} \cdot \frac{CMNewFloorspace_{r,b,y}}{TotalFloorspace_{r,b,y}} \right) \quad (\text{B - 37})$$

$s \in \{ Solar Services \}$

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

$$RetireServDmd_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \cdot \sum \left( \frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}} \right) \quad (\text{B - 38})$$

$\forall t \ni TechbyService = 1$

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

$$ServDmdSurv_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - RetireServDmd_{s,b,r,y} \quad (\text{B - 39})$$

$y > CMFirstYr$

## Technology Choice Equations

Proportion of service demand affected by failed equipment:

$$ReplacementProportion_{r,b,s} = \sum \left( \frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}} \right) \quad (\text{B - 40})$$

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

Equipment share of service demand not requiring equipment replacement:

$$SurvivingShareofService_{r,b,s,t,v} = PrevYrTechShareofService_{r,b,s,t,v} \cdot \frac{\left( 1 - \frac{1}{TechLife_{t,v}} \right)}{1 - ReplacementProportion_{r,b,s}} \quad (\text{B - 41})$$

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

Fuel shares of service demand not requiring equipment replacement:

$$SurvivingFuelShareofService_{r,b,s,t,v} = \sum \left[ SurvivingShareofService_{r,b,s,t,v} \cdot FuelbyTech_{t,f} \right] \quad (\text{B - 42})$$

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

Failed equipment shares of service demand requiring equipment replacement:

$$ReplacementShareofService_{r,b,s,t,v} = \frac{PrevYrTechShareofService_{r,b,s,t,v} \cdot \left[ \frac{1}{TechLife_{t,v}} \right]}{ReplacementProportion_{r,b,s}} \quad (\text{B - 43})$$

Fuel shares of service demand requiring equipment replacement:

$$ReplacementFuelShareofService_{r,b,s,f} = \sum_{\forall t,v \ni TechbyService_{s,t}=1} (ReplacementShareofService_{r,b,s,t,v} \cdot FuelbyTech_{t,f}) \quad (\text{B - 44})$$

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

$$TechCost_{t,v,1} = TechCost_{t,v,1} - TechCost_{CoolingTechIndexHP,v,1} \quad (\text{B - 45})$$

$t,v \in \{Heatpumps \text{ for } SpHeat\}$

This is a one-time adjustment performed following the input of *TechCost* from the KTECH file.

Cost Trend Function when flag *CostTrendSwitch* is set to one:

$$KEqCost(t,v,y,"CAP") \equiv \frac{TechCost_{t,v,1} \cdot \delta}{1 + \left(\frac{y-y_1}{y_0-y_1}\right)^\gamma} + (1-\delta) \cdot TechCost_{t,v,1}, \quad \text{for Infant technologies}$$

$$\frac{TechCost_{t,v,1} \cdot 2 \cdot \delta}{1 + \left(\frac{y-y_1}{y_0-y_1}\right)^\gamma} + (1-\delta) \cdot TechCost_{t,v,1}, \quad \text{for Adolescent technologies}$$

$$TechCost_{t,v,1}, \quad \text{for Mature technologies}$$

(B - 46)

$\gamma \equiv$  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:

$$\begin{aligned} ShellEffFactor_x &= ShellEffIndex_{b,r,x} \\ s &\in \{SpHeat\} \end{aligned} \tag{B - 47}$$

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

$$\begin{aligned} ShellEffFactor_1 &= (ShellEffIndex_{b,r,1} - 1) \cdot -0.1 + 1.002 \\ ShellEffFactor_2 &= (ShellEffIndex_{b,r,2} \cdot NewShAdj - 1) \cdot -0.0309 + 1.0315 \\ s &\in \{SpCool\} \end{aligned} \tag{B - 48}$$

Effective hurdle (implicit discount) rate:

$$Hurdle = \frac{MC\_REALRMGBLUS_y}{100} + TimePrefPrem_{s,p,y} \tag{B - 49}$$

$$\begin{aligned} EffectHurdle \equiv & \quad Hurdle, & \quad \text{for } Hurdle \leq 0.15 \\ & & \quad \text{or} \\ & & \quad Pr_{f,r,y,s} \leq Pr_{f,r,CBECYear,s} \\ & & \quad \tag{B - 50} \\ & \quad 0.15 + (Hurdle - 0.15) \cdot \left( \frac{Pr_{f,r,y,s}}{Pr_{f,r,CBECYear,s}} \right)^{HurdleElas_{r,s,f}}, & \quad \text{otherwise} \end{aligned}$$

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). The subscript  $y$  is expressed as a calendar year in the third term.

**Annualized cost of new equipment:**

$$\begin{aligned}
 AnnualCostTech_{p,t,v} = & KEqCost(t,v,y,"CAP") \cdot \frac{EffectHurdle}{1 - (1 + EffectHurdle)^{-TechLife_{t,v}}} \\
 & + TechCost_{t,v,2} \cdot CapacityFactor_{r,b,s} \\
 & + ShellEffFactor_x \cdot \frac{ConvFactor}{TechEff_{r,s,t,v}} \cdot CapacityFactor_{r,b,s} \cdot FuelCost_{f,r,y,s} \quad \text{(B - 51)}
 \end{aligned}$$

$$ConvFactor \equiv 8.76 \text{ for } s \neq \text{lighting}; 0.3343^{-1} \text{ for } s = \text{lighting}$$

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

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-48 and B-49. 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*<sub>f,r,y,s</sub> 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-51 when optional price expectations modeling is used.

**Expression for FuelCost when optional price expectations are used:**

$$FuelCost_{f,r,y,s} \equiv \frac{1}{TechLife_{t,v}} \cdot \sum_{y'=y}^{y + TechLife_{t,v} - 1} Xprice_{f,r,y'} \quad \text{(B - 52)}$$

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

**Least Cost Decision Rule -- identify least cost equipment:**

$$\begin{aligned}
 & \text{Find } t,v \text{ such that } AnnualCostTech_{p,t,v} \leq AnnualCostTech_{p,t',v'} \forall t',v' \\
 & \text{then } LCTNRAF_{p,1} = t \text{ and } LCTNRAF_{p,2} = v \quad \text{(B - 53)}
 \end{aligned}$$

LCTNRAF<sub>p,1</sub> represents the technology class with the least annualized cost.

LCTNRAF<sub>p,2</sub> 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**

$$\begin{aligned}
 & \text{Find } t, v \ni \text{AnnualCostTech}_{p,t,v} \leq \text{AnnualCostTech}_{p,t',v'} \quad \forall t', v' \ni \text{FuelByTech}(t', f) = \text{FuelByTech}(t, f) = 1, \\
 & \text{then } \text{LCTNRSF}_{p,f,1} = t \text{ and } \text{LCTNRSF}_{p,f,2} = v. \\
 & \text{If } \exists t \ni \text{FuelByTech}(t, f) = 1, \text{ then } \text{LCTNRSF}_{p,f,1} = \text{LCTNRSF}_{p,f,2} = 0 \\
 & f \in \{ \text{Major Fuels} \}
 \end{aligned}
 \tag{B - 54}$$

Where LCTNRSF<sub>p,f,1</sub> represents the technology class with the least annualized cost, and LCTNRSF<sub>p,f,2</sub> represents the technology model with the least annualized cost.

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

$$\begin{aligned}
 & \text{Find } v \text{ such that } \text{AnnualCostTech}_{p,t,v} \leq \text{AnnualCostTech}_{p,t,v'} \quad \forall v' \\
 & \text{then } \text{LCVNRST}_{p,t} = v
 \end{aligned}
 \tag{B - 55}$$

LCVNRST<sub>p,t</sub> represents the technology model with the least annualized cost.

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

$$\begin{aligned}
 \text{LCMSNR}_{t,v} &= \sum_p \text{TimePrefProp}_{s,p,y} \\
 &\forall p \ni \text{LCTNRAF}_{p,1} = t \text{ and } \text{LCTNRAF}_{p,2} = v
 \end{aligned}
 \tag{B - 56}$$

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

$$\begin{aligned}
 \text{SFMSN}_{t,v} &= \sum [ \text{TimePrefProp}_{s,p,y} \cdot \text{PrevYrFuelShareofService}_{r,b,s,f} ] \\
 &\forall p \ni \text{LCTNRSF}_{p,f,1} = t, \text{ and } \text{LCTNRSF}_{p,f,2} = v; f \in \{ \text{MajFuels} \}
 \end{aligned}
 \tag{B - 57}$$

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

$$SFMSR_{t,v} = \sum_{\forall p \ni LCTNRSF_{p,f,1}=t, \text{ and } LCTNRSF_{p,f,2}=v; f \in \{MajFuels\}} [TimePrefProp_{s,p,y} \cdot ReplacementFuelShareofService_{r,b,s,f}] \quad (\text{B - 58})$$

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

$$STMSN_{t,v} = \left[ \sum_{\forall p \ni LCVNRST_{p,t}=v} TimePrefProp_{s,p,y} \right] \cdot \left[ \sum_{\forall v'} PrevYrTechShareofService_{r,b,s,t,v'} \right] \quad (\text{B - 59})$$

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

$$STMSR_{t,v} = \left[ \sum_{\forall p \ni LCVNRST_{p,t}=v} TimePrefProp_{s,p,y} \right] \cdot \left[ \sum_{\forall v'} ReplacementShareofService_{r,b,s,t,v'} \right] \quad (\text{B - 60})$$

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

$$\begin{aligned} MS_{b,s,1,t,v} &= BehaviorShare_{s,b,1,1} \cdot LCMSNR_{t,v} \\ &+ BehaviorShare_{s,b,1,2} \cdot SFMSN_{t,v} \\ &+ BehaviorShare_{s,b,1,3} \cdot STMSN_{t,v} \end{aligned} \quad (\text{B - 61})$$

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:

$$\begin{aligned}
 MS_{b,s,2,t,v} &= BehaviorShare_{s,b,2,1} \cdot LCMSNR_{t,v} \\
 &+ BehaviorShare_{s,b,2,2} \cdot SFMSR_{t,v} \\
 &+ BehaviorShare_{s,b,2,3} \cdot STMSR_{t,v}
 \end{aligned}
 \tag{B - 62}$$

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:

$$\begin{aligned}
 ACE_{t,v,p} &= TechCost_{t,v,2} \cdot CapacityFactor_{r,b,s} \\
 &- RetroCostFract_{t,v} \cdot KEqCost(t,v,y,"CAP") \cdot \frac{EffectHurdle}{1 - (1 + EffectHurdle)^{-TechLife_{t,v}}} \\
 &+ ShellEffFactor_1 \cdot \frac{ConvFactor}{TechEff_{r,s,t,v}} \cdot \frac{CapacityFactor_{r,b,s}}{\frac{1}{2} \cdot TechLife_{t,v}} \cdot \sum_{y'=y}^{y + \frac{1}{2} \cdot TechLife_{t,v} - 1} Xprice_{f_t,r,y'}
 \end{aligned}
 \tag{B - 63}$$

$ConvFactor \equiv 8.76$  for  $s \neq \text{lighting}$ ;  $0.3343^{-1}$  for  $s = \text{lighting}$

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

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-48 and B-49. 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.

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

$$\begin{aligned}
 & \text{Find } t', v' \text{ such that } AnnualCostTech_{p,t',v'} \leq ACE_{t,v,p} \\
 & \text{if none found, set } t' = t, v' = v. \\
 & \text{If } t, v \text{ unavailable, set } t' = v' = 0 \\
 & \text{then } LCTRetAF_{p,t,v,1} = t', LCTRetAF_{p,t,v,2} = v'
 \end{aligned}
 \tag{B - 64}$$

Identify least cost retrofit alternative for same fuel behavior:

$$\begin{aligned}
 & \text{Find } t', v' \ni AnnualCostTech_{p,t',v'} \leq ACE_{t,v,p}, f_{t'} = f_t \\
 & \text{If } \exists t', v', \text{ set } t' = t, v' = v \\
 & \text{If } \nexists t, v, \text{ set } t' = v' = 0 \\
 & \text{then } LCTRetSF_{p,t,v,1} = t', LCTRetSF_{p,t,v,2} = v'
 \end{aligned}
 \tag{B - 65}$$

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

$$\begin{aligned}
 & \text{Find } v' \ni AnnualCostTech_{p,t,v'} \leq ACE_{t,v,p}, \forall v' \\
 & \text{If } \exists v', \text{ set } v' = v \\
 & \text{then } LCVRetST_{p,t,v} = v'
 \end{aligned}
 \tag{B - 66}$$

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

$$\begin{aligned}
 LCMSRet_{t,v} &= \sum [TimePrefProp_{s,p,y} \cdot SurvivingShareofService_{t',v'}] \\
 & \forall t', v' \ni LCTRetAF_{p,t',v',1} = t, LCTRetAF_{p,t',v',2} = v; \forall p
 \end{aligned}
 \tag{B - 67}$$

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

$$\begin{aligned}
 SFMSRet_{t,v} &= \sum [TimePrefProp_{s,p,y} \cdot SurvivingShareofService_{t',v'}] \\
 & \forall t', v' \ni LCTRetSF_{p,t',v',1} = t, LCTRetSF_{p,t',v',2} = v; \forall p
 \end{aligned}
 \tag{B - 68}$$

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



Amount of cooling service demand satisfied by heat pumps:

$$HeatPumpCoolingSD_d = SD_{s=SpCool,d} \cdot \sum_{t,v \in \{Heatpumps \text{ for } SpCool\}} MS_{b,s=SpCool,d,t,v} \quad (\text{B - 72})$$

$$Normalizer_d = \sum_{t,v \in \{SpCool \text{ equip other than heatpumps}\}} MS_{b,s=SpCool,d,t,v} \quad (\text{B - 73})$$

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

$$MS_{b,s=SpCool,d,t,v} = \frac{MS_{b,s=SpCool,d,t,v}}{Normalizer_d} \cdot \frac{(SD_{s=SpCool,d} - HeatPumpCoolingSD_d)}{SD_{s=SpCool,d}} \quad (\text{B - 74})$$

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

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

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

0, elsewhere (B - 75)

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

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

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

(B - 76)

0, otherwise

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

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

$$\begin{aligned}
 FuelShareofService_{r,b,s,f} &= \frac{NSD_{r,b,s,y} \times FS_{r,b,s,1,f}}{TSD_{r,b,s,y}} \\
 &+ \frac{RSD_{r,b,s,y} \times FS_{r,b,s,2,f}}{TSD_{r,b,s,y}} + \frac{SSD_{r,s,b,y} \times FS_{r,b,s,3,f}}{TSD_{r,b,s,y}}
 \end{aligned}
 \tag{B - 77}$$

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:**

$$\begin{aligned}
 TechShareofService_{r,b,s,t,v} &= \frac{NSD_{r,b,s,y} \times MS_{r,b,s,1,t,v}}{TSD_{r,b,s,y}} \\
 &+ \frac{RSD_{r,b,s,y} \times MS_{r,b,s,2,t,v}}{TSD_{r,b,s,y}} + \frac{SSD_{r,s,b,y} \times MS_{r,b,s,3,t,v}}{TSD_{r,b,s,y}}
 \end{aligned}
 \tag{B - 78}$$

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

$\forall t , v$

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

$$\begin{aligned}
 AverageEfficiency_{r,b,s,f} &= \frac{FuelShareofService_{r,b,s,f}}{\sum_{t,v} \left[ \frac{TechShareofService_{r,b,s,t,v} \times FuelbyTech_{t,f}}{TechEff_{r,s,t,v}} \right]}
 \end{aligned}
 \tag{B - 79}$$

if  $\exists t \ni TechShareofService_{r,b,s,t,v} \times FuelbyTech_{t,f} \neq 0$   
 0, otherwise

$f \in \{MajFuels\}$

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

$$DecAvgEff_{r,s,1,f,y} = \frac{\sum_b [FS_{r,b,s,1,f} \times NSD_{r,b,s,y}]}{\sum_b \left[ \frac{FS_{r,b,s,1,f} \times NSD_{r,b,s,y}}{AE_{r,b,s,1,f}} \right]} \quad (\text{B} - 80)$$

$f \in \{MajFuels\}$

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:

$$DecAvgEff_{r,s,2,f,y} = \frac{\sum_b [FS_{r,b,s,2,f} \times RSD_{r,b,s,y}]}{\sum_b \left[ \frac{FS_{r,b,s,2,f} \times RSD_{r,b,s,y}}{AE_{r,b,s,2,f}} \right]} \quad (\text{B} - 81)$$

$f \in \{MajFuels\}$

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

$$DecAvgEff_{r,s,3,f,y} = \frac{\sum_b [FS_{r,b,s,3,f} \times SSD_{r,b,s,y}]}{\sum_b \left[ \frac{FS_{r,b,s,3,f} \times SSD_{r,b,s,y}}{AE_{r,b,s,3,f}} \right]} \quad (\text{B} - 82)$$

$f \in \{MajFuels\}$

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

$$DecFuelShare_{r,s,1,f,y} = \frac{\sum_b [FS_{r,b,s,1,f} \times NSD_{r,b,s,y}]}{\sum_b NSD_{r,b,s,y}} \quad (\text{B} - 83)$$

$f \in \{MajFuels\}$

The third subscript of DecFuelShare represents decision type, d.

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

$$DecFuelShare_{r,s,2,f,y} = \frac{\sum_b [FS_{r,b,s,2,f} \times RSD_{r,b,s,y}]}{\sum_b RSD_{r,b,s,y}} \quad (B - 84)$$

$f \in \{MajFuels\}$

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

$$DecFuelShare_{r,s,3,f,y} = \frac{\sum_b [FS_{r,b,s,3,f} \times SSD_{r,b,s,y}]}{\sum_b SSD_{r,b,s,y}} \quad (B - 85)$$

$f \in \{MajFuels\}$

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

$$CMUSAvgEff_{s,f,y} = \frac{\sum_r \sum_b [FuelShareofService_{r,b,s,f} \times TSD_{r,b,s,y}]}{\sum_r \sum_b \sum_{t,v} \left[ \frac{TechShareofService_{r,b,s,t,v} \times FuelbyTech_{t,f} \times TSD_{r,b,s,y}}{TechEff_{r,s,t,v}} \right]} \quad (B - 86)$$

$s \in \{MajServ\}, f \in \{MajFuels\}$

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

$$AverageEfficiency_{r,b,s,f} = PrevYrAverageEfficiency_{r,b,s,f} \times (1 + EffGrowthRate_s) \quad (B - 87)$$

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

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

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

$$DecFuelShare_{r,s,d,f,y} = FuelShrofService_{r,b,s,1} \quad (B - 88)$$

$s \in \{MinServ\}$

## End-Use Fuel Consumption Equations

Basic estimate of fuel consumption to meet end-use demands other than lighting:

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

**(B - 89)**

$$0, \text{ otherwise}$$

$s \neq \text{lighting}, f \in \{MajFuels\}$

Basic estimate of fuel consumption by lighting equipment:

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

**(B - 90)**

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

Modification of fuel consumption by Price Elasticity and Rebound Effect:

$$EndUseConsump_{f,s,b,r,y} = EndUseConsump_{f,s,b,r,y} \cdot \left( 1 + \left[ \frac{Pr_{f,r,y,s} - Pr_{f,r,CBECsYear,s}}{Pr_{f,r,CBECsYear,s}} \right] \cdot \varepsilon_1 \right)$$

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

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

**(B - 91)**

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

evaluated without building shell effect (third term) for  
 $s \in \{\text{water htg, ventilation, cooking, and lighting}\}$

evaluated without equipment and building shell efficiency effects (second and third term) for  
 $s \in \{\text{refrigeration, all office equipment, and other uses}\}$

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).  $\varepsilon_n$  is the elasticity parameter, where  $n = 1$  for the short-term price elasticity for Census division  $r$  and service  $s$  and  $n = 2$  for the rebound elasticity.

**Weather Correction:**

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

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

$$f \in \{MajFuels\}$$

$$wthryr \equiv \begin{cases} y, & \text{if } y \leq KSTEOYR \\ KSTEOYR, & \text{if } y > KSTEOYR \end{cases}$$
**(B - 92)**

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

$$ElShr_s = \frac{EndUseConsump_{1,s,b,r,y}}{\sum_s EndUseConsump_{1,s,b,r,y}}$$
**(B - 93)**

Where 1 is the fuel subscript representing electricity.

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

$$EndUseConsump_{1,s,b,r,y} = EndUseConsump_{1,s,b,r,y} - \sum_{t \neq PV} Trills_{y,r,b,t} \cdot ElShr_s$$
**(B - 94)**

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:**

$$EndUseConsump_{1,2,b,r,y} = EndUseConsump_{1,2,b,r,y} - Trills_{y,r,b,1} \cdot 0.67$$

$$EndUseConsump_{1,6,b,r,y} = EndUseConsump_{1,6,b,r,y} - Trills_{y,r,b,1} \cdot 0.165$$

$$EndUseConsump_{1,10,b,r,y} = EndUseConsump_{1,10,b,r,y} - Trills_{y,r,b,1} \cdot 0.165$$
**(B - 95)**

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 PV systems. 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 cogeneration:**

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

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

**(B - 96)**

$\forall t$  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.

**Addition of Consumption of major fuels by distributed generation and cogeneration technologies:**

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

**(B - 97)**

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

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.

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

$$\begin{aligned}
DistServConsump_{r,b,s,f,y} &= DistServSteamEUI_{r,b,s} \\
&\times (SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}) \\
&\times \left( \frac{DistServFuelShr_{b,f}}{DistServBoilerEff_f} \right) \\
&\times 10^{-3}
\end{aligned} \tag{B - 98}$$

$s \in \{DistServ\}; f \in \{MajFuels\}$

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

$$\begin{aligned}
DistServConsump_{r,b,s,f,y} &= DistServConsump_{r,b,s,f,y} \\
&\times \left( 1 + \left[ \frac{Pr_{f,r,y,s} - Pr_{f,r,CBECYear,s}}{Pr_{f,r,CBECYear,s}} \right] \cdot \epsilon_1 \right) \\
&\times \frac{DegreeDays_{s,r,withyr}}{DegreeDays_{s,r,CBECYear}}
\end{aligned} \tag{B - 99}$$

$s \in \{SpHeat + SpCool\}$   
 $f \in \{MajFuels\}$   
 $withyr = \begin{cases} y, & \text{if } y \leq KSTEOYR \\ KSTEOYR, & \text{if } y > KSTEOYR \end{cases}$

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

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

$$\begin{aligned}
CMUSDistServ_{s,f,y} &= \left[ \sum_r \sum_b DistServConsump_{r,b,s,f,y} \right] \times 10^{-3} \\
s &\in \{DistServ\}; f \in \{MajFuels\}
\end{aligned} \tag{B - 100}$$

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

$$\begin{aligned}
 EndUseConsump_{f,s,b,r,y} &= EndUseConsump_{f,s,b,r,y} \\
 &+ DistServConsump_{r,b,s,f,y} \quad \text{(B - 101)} \\
 f &\in \{MajFuels\}
 \end{aligned}$$

**Total fuel consumption across end-use services:**

$$\begin{aligned}
 FinalEndUseCon_{f,b,r,y} &= \sum_s EndUseConsump_{f,s,b,r} \\
 f &\in \{MajFuels\} \quad \text{(B - 102)}
 \end{aligned}$$

**Unbenchmarked fuel consumption forecast by Census division and building type:**

$$\begin{aligned}
 UnBenchCon_{f,r,b,y} &= FinalEndUseCon_{f,b,r,y} \\
 f &\in \{MajFuels\} \quad \text{(B - 103)}
 \end{aligned}$$

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

$$\begin{aligned}
 CMUSConsump_{s,f,y} &= \left[ \sum_r \sum_b EndUseConsump_{f,s,b,r,y} \right] \times 10^{-3} \\
 f &\in \{MajFuels\} \quad \text{(B - 104)}
 \end{aligned}$$

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

$$\begin{aligned}
 CMUSAvgEff_{s,f,y} &= \frac{\sum_r \sum_b [FuelShareofService_{r,b,s,f} \times TSD_{r,b,s,y}]}{CMUSConsump_{s,f,y} \times 10^3} \quad \text{(B - 105)} \\
 \forall s &\in \{MinServ\}, f \in \{MajFuel\}
 \end{aligned}$$

Consumption of minor fuels other than motor gasoline:

$$\begin{aligned} FinalEndUseCon_{f,b,r,y} &= (e^{MinFuelAlpha_{r,f-CMnumMajFl}} \\ &x Price_{f,r,y}^{MinFuelBeta_{r,f-CMnumMajFl}} \\ &x 10^{-6} \\ &x (SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}) \end{aligned} \tag{B - 106}$$

$\forall f \in \{MinFuels\} - \{MotorGasoline\}, b, r; y$

Consumption of motor gasoline during historical and near term periods:

$$FinalEndUseCon_{f,b,r,y} = \frac{CMSEDS_{f,r,y} - TranFromSEDS_{f,y,r} - NUGFromSEDS_{f,y,r}}{CMnumBldg} \quad (\text{B - 107})$$

$f = MotorGasoline$ ;  $y \leq KSTEOYR$

Consumption of motor gasoline beyond near term period:

$$FinalEndUseCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y-1} \cdot (1 + MinFuelBeta_{r,f-CMnumMajFl}) \quad (\text{B - 108})$$

$f \in \{MotorGasoline\}$ ;  $y > KSTEOYR$ ;  $\forall b,r$

Unbenchmarked consumption of fuels across end-uses, by Census division:

$$CMFinalUnbenchCon_{f,r,y} = \sum_b UnBenchCon_{f,b,r,y} \quad (\text{B - 109})$$

$\forall f \in \{MajFuels\}$

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

$$CMFinalEndUse_{f,r,y} = \sum_b FinalEndUseCon_{f,b,r,y} \quad (\text{B - 110})$$

$f \in \{MajFuels + MinFuels + RenewableFuels\}$

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

$$CMFinalEndUseCon_{b,y} = \sum_r \sum_{\substack{f \\ \forall f \in \{MajFuels + MinFuels + RenewableFuels\}}} FinalEndUseCon_{f,b,r,y} \quad (\text{B - 111})$$

$$+ \sum_r \sum_s \frac{SolarRenewableContrib_{r,s,y}}{CMnumBldg}$$

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

## Benchmarking Equations

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

$$\begin{aligned}
 SEDSMistie_{f,r,[y]} &= CMSEDS_{f,r,y} - CMFinalEndUse_{f,r,y} \\
 y &\leq MSEDYR + 1 \\
 f &\in \{MajFuels + MinFuels\}
 \end{aligned}
 \tag{B - 112}$$

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

Nonbuilding fuel use forecast for historical years:

$$\begin{aligned}
 CMNonBldgUse_{f,r,y} &= SEDSMistie_{f,r,[y]} \\
 y &\leq MSEDYR + 1
 \end{aligned}
 \tag{B - 113}$$

Difference between forecasted fuel use (non-distillate, non-residual) with SEDS nonbuilding component, and STEO forecast:

$$\begin{aligned}
 STEOMistie_{f,r,[y]} &= (CMSEDS_{f,r,y} - TranFromSEDS_{f,r,y} - NUGFromSEDS_{f,r,y}) \\
 &- (CMFinalEndUse_{f,r,y} + SEDSMistie_{f,r,[MSEDYR+1]} + \\
 &\frac{(MC\_COMMFLSP_{r,1,y} - MC\_COMMFLSP_{r,1,y'=MSEDYR+1})}{MCCOMMFLSP_{r,1,y'=MSEDYR+1}} \cdot |SEDSMistie_{f,r,[MSEDYR+1]}|)
 \end{aligned}
 \tag{B - 114}$$

$$\begin{aligned}
 MSEDYR + 1 &< y \leq KSTEOYR \\
 f &\in \{MinFuels + MajFuels \text{ except Distillate and Residual}\}
 \end{aligned}$$

SEDS-based component of nonbuilding fuel use (non-distillate, non-residual) after last year of available SEDS data:

$$\begin{aligned}
 CMNonBldgUse_{f,r,y} &= SEDSMistie_{f,r,[MSEDYR+1]} + \\
 &\left( \frac{MC\_COMMFLSP_{r,1,y} - MC\_COMMFLSP_{r,1,MSEDYR+1}}{MC\_COMMFLSP_{r,1,MSEDYR+1}} \right) \cdot |SEDSMistie_{f,r,[MSEDYR+1]}|
 \end{aligned}
 \tag{B - 115}$$

$$\begin{aligned}
 y &> MSEDYR + 1 \\
 f &\in \{MinFuels + MajFuels \text{ except Distillate and Residual}\}
 \end{aligned}$$

Difference between forecasted distillate or residual fuel consumption with SEDS nonbuilding component, and STEO forecast:

$$\begin{aligned}
 STEOMistie_{f,r,[y]} = & (CMSEDS_{f,r,y} - TranFromSEDS_{f,r,y} - NUGFromSEDS_{f,r,y}) \\
 & - (CMFinalEndUse_{f,r,y} + SEDSMistie_{f,r,[MSEDYR+1]})
 \end{aligned}
 \tag{B - 116}$$

$$\begin{aligned}
 & MSEDYR + 1 < y \leq KSTEOYR \\
 & f \in \{Distillate, Residual\}
 \end{aligned}$$

SEDS-based component of nonbuilding distillate or residual fuel consumption:

$$\begin{aligned}
 CMNonBldgUse_{f,r,y} = & SEDSMistie_{f,r,[MSEDYR+1]} \\
 & y > MSEDYR + 1 \\
 & f \in \{Distillate, Residual\}
 \end{aligned}
 \tag{B - 117}$$

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

$$\begin{aligned}
 CMNonBldgUse_{f,r,y} = & CMNonBldgUse_{f,r,y} + STEOMistie_{f,r,[y]}, \text{ if } STEOBM = 1 \\
 & \text{and} \\
 & ComSTEOBM = 1 \\
 & \text{unchanged, otherwise}
 \end{aligned}
 \tag{B - 118}$$

$$\begin{aligned}
 & MSEDYR + 1 < y \leq KSTEOYR \\
 & f \in \{Major \text{ and } minor \text{ fuels}\}
 \end{aligned}$$

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

$$\begin{aligned}
 STEOTieDecayFactor_{[y]} = & 1, & \text{ if } DecayBM = 0 \\
 & 1 - \frac{(y - KSTEOYR)}{(FirstNonBenchYr - KSTEOYR)}, & \text{ if } DecayBM = 1 \\
 & 0, & \text{ if } DecayBM = 1 \text{ and } \\
 & & y \geq FirstNonBenchYr
 \end{aligned}
 \tag{B - 119}$$

Where *FirstNonBenchYr* is converted from a calendar year to a year index prior to use.

**Optional STEO-based component of nonbuilding fuel consumption forecast after last year of available STEO data:**

$$CMNonBldgUse_{f,r,y} = CMNonBldgUse_{f,r,y} + STEOMistie_{f,r,[KSTEOYR]} \cdot STEOTieDecayFactor_{[y]},$$

*if STEOBM = 1;*  
*unchanged, otherwise*

**(B - 120)**

**Final benchmarked fuel consumption forecast by fuel, Census division, and year:**

$$CMFinalEndUse_{f,r,y} = CMFinalEndUse_{f,r,y} + CMNonBldgUse_{f,r,y}$$

*f* ∈ { *Major and minor fuels* }

**(B - 121)**

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

$$PriceDelta_{f,y} = \frac{(Price_{f,11,y} + Price_{f,11,y-1} + Price_{f,11,y-2}) \times 0.333}{Price_{f,11,Baseyear}}$$

*f* ∈ { *MajorFuels* }; *y* > *KSTEOYR*

**(B - 122)**

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:**

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

*f* ∈ { *MajorFuels* }; *y* > *KSTEOYR*

**(B - 123)**

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

$$\begin{aligned} \text{YearsForward}_{t,v,y} \equiv & \quad IFMAX , & \quad \text{if } IFMAX \leq \text{ShiftYears}_{t,v} \\ & \text{ShiftYears}_{t,v} , & \quad \text{if } \text{YearsForward}_{t,v,y-1} < \text{ShiftYears}_{t,v} < IFMAX \\ & \text{YearsForward}_{t,v,y-1} , & \quad \text{elsewhere} \end{aligned} \quad (\mathbf{B - 124})$$

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.

## Distributed Generation and Cogeneration Equations

$$equipmentcost = \min \left\{ menucost, c0 * cumship^{-beta} \right\} \quad (\text{B - 125})$$

Technology learning effects on installed cost of emerging technologies:

where  $c0$  and  $beta$  are technology-specific learning cost parameters, and  $cumship$  represents cumulative shipments for residential and commercial buildings combined.

The loan amortization formula annual levelized payment calculation:

$$payment = equipmentcost - downpay \cdot \frac{intrate}{\left[ 1 - (1 + intrate)^{-term} \right]} \quad (\text{B - 126})$$

where the first term in brackets is the amount financed,  $intrate$  is the interest rate for the loan and  $term$  is the loan term over which the payments are amortized. The variable  $equipmentcost$  is the sum of installation cost plus capital cost times the purchased capacity (kw).<sup>1</sup>

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

$intamt$  – 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,  $loanbal_{y-1}$ , times the mortgage interest rate.

$prin$  – the amount principal paid on the loan in each year of the analysis – used to determine the loan balance for the next year of the analysis. It is computed as the difference between the levelized payment

$$prin_y = payment_y - intamt_y \quad (\text{B - 127})$$

and the interest paid:

---

<sup>1</sup> For readability, the variable names here omit a coding convention of beginning real variable names with "x", integers with "i" and string variables with "a".

loanbal – principal balance of the loan for each year of the analysis. This variable is used to compute the current year's intamt. The loan balance reduces over time according to the formula:

$$loanbal_y = loanbal_{y-1} - prin_y \quad (\text{B - 128})$$

depr – computed straight line depreciation amount:

$$depr_{t,v} = (instcost_{t,v} + capcost_{t,v}) * kw_t / txlife_{t,v} \quad (\text{B - 129})$$

taxcredit – computed tax credit for investments appropriate investments (there is currently a tax credit for photovoltaics under the EPACT).

$$taxcredit_{t,v} = \text{maximum} \left\{ (instcost_{t,v} + capcost_{t,v}) \cdot taxcreditpct_{t,v}; \right. \\ \left. taxcreditmax_{t,v} \right\} \quad (\text{B - 130})$$

taxdeduct – current year tax deduction for investment.

$$taxdeduct_y = taxrate \cdot (intamt_{y-1} + depr_{y-1}) + taxcredit_y \quad (\text{B - 131})$$

**Annual kWh generated by technology:**

annualkwh – represents annual system kWh generation 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:

$$annualkwh_{t,v} = eleff_{t,v} \cdot solarins_r \cdot modulesquft_{t,v} \cdot lossfac_{t,v} \cdot kw_{t,v} \quad (\text{B - 132})$$

for technology, t; vintage, v; and Census division, r.

The variable for estimated PV array square footage for a 1-kw system, *modulesqft*, is computed as follows:

$$modulesqft_{t,v} = \frac{346.78}{5.0} \cdot \frac{0.18}{eff_{t,v}} \quad (\text{B - 133})$$

Note, the lower the efficiency, the greater the square footage required for a 1-kw system.

For other technologies ( $t > 1$ ), annual system generation is determined by system capacity, and hours of use as follows:

$$annualkwh_{t,v} = operhours_t \cdot avail_{t,v} \cdot lossfac_{t,v} \cdot kw_t \quad (\text{B - 134})$$

*kwh* – 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 for all years following the base year of the cashflow analysis ( $y \geq 3$ ).

$$kwh_{t,v,y} = annualkwh_{t,v} \cdot [1 + deged_{t,v}]^{(y-2)} \quad (\text{B - 135})$$

where  $y$  is the cashflow model year. Year 1 is the purchase year during which no savings or expenses other than the loan downpayment occurs. It can be viewed as an end of year purchase. Year 2 is the first year of operation, or the “base year,” year 3 is the start of the degradation calculations.

**Fuel consumption of fuel using distributed generation technologies:**

*fuelinput* – MMBtu of the input fuel used by the technology:

$$fuelinput_{t,v} = .003412 \cdot \frac{operhours_t \cdot avail_{t,v}}{eleff_{t,v}} \quad (\text{B - 136})$$

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

btuwasteheat – computed waste heat available for water heating (valid only for fuel cells or other fuel-consuming generating technologies)

$$btuwasteheat_{t,v} = [fuelinput_{t,v} - .003412 \cdot annualkwh_{t,v}] \cdot whrecovery_{t,v} \quad (\text{B - 137})$$

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

$$waterhtgmmbtu_{t,v} = maximum \left\{ \begin{array}{l} btuwasteheat_{t,v}, \\ average\ water\ heating\ mmBtu_{r,b} \end{array} \right\} \quad (\text{B - 138})$$

$$spacehtgmmbtu_{t,v} = maximum \left\{ \begin{array}{l} btuwasteheat_{t,v} - waterhtgmmbtu_{t,v}, \\ average\ space\ heating\ mmBtu_{r,b} \end{array} \right\} \quad (\text{B - 139})$$

Net fuel cost and value of electricity savings calculations:

baseyrfuelcost – initial fuel costs (in 1987 dollars) for operating the generation technology. Calculated from the fuel price and fuel input

$$baseyrfuelcost_{t,v} = [fuelinput_{t,v} - waterhtgmmbtu_{t,v} - spacehtgmmbtu_{t,v}] \cdot fuelprice_r \quad (\text{B - 140})$$

fuelcost – nominal dollar value fuel cost for the technology net of any water heating cost savings from using waste heat

$$fuelcost_{t,v} = baseyrfuelcost_{t,v} \cdot [1 + inflation]^{(y-2)} \quad (\text{B - 141})$$

valesavebase – calculated value of generated electricity

Case 1: Photovoltaics

If generation is less than average electricity usage for the building type, (i.e.,  $annualkwh \leq elecavgkwh$ ), then savings are valued at the air conditioning price (since photovoltaic maximums correlate with the air conditioning season):

$$pelcmout_{r,y,air\ conditioning} * annualkwh_{t,v} * .003412$$

If generation exceeds average usage, then the excess kWh are sold to the grid and the value is:

$$\left[ pelcmout_{r,y,air\ conditioning} \cdot elecavgkwh + pelmer,y \cdot excesskwh \right] \cdot .003412 \quad (\text{B - 142})$$

Case 2 all other technologies:

The air conditioning price,  $pelcmout_{r,y,air\ conditioning}$ , is replaced by  $pelcm_{r,y}$ , the average electricity price.

valesave – computed as the nominal dollar value of valesavebase with an adjustment for output degradation (if appropriate)

$$valesave_v = valesavebase \cdot [1 + inflation]^{(y-2)} \cdot [1 + degraded]^{(y-2)} \quad (\text{B - 143})$$

excesskwh – generated kWh in excess of average commercial usage. Excess kWh are valued at the grid sales price (currently the commercial retail rate for photovoltaics and the price of marginal electricity purchases (by the utility) for other technologies.

**Maintenance cost calculations:**

maintcost – nominal dollar cost of maintenance cost from the input file (per kw) for the specific technology and vintage being analyzed

$$maintcost_{t,v} = baseymaintcost_{t,v} \cdot [1 + inflation]^{(y-2)} \quad (\text{B - 144})$$

**Cashflow, cumulative cashflow and simplepayback years:**

$$\begin{aligned} netcashflow_{t,v,y} = & valesave_y + taxdeduct_y - payment_y \\ & - fuelcost_y - maintcost_y \end{aligned} \quad (\text{B - 145})$$

cumnetcashflow<sub>y</sub> – is defined as the accumulated sum of all prior “netcashflow” amounts.

simplepayback -- defined as the first year in the cashflow stream for which an investment has a positive cumulative net cashflow (i.e., if and when cumnetcashflow >=0).

**Maximum penetration into new construction:**

$$maxpen_{t,v} = \frac{penparm_{t,v}}{simplepayback_{t,v}} \quad (\text{B - 146})$$

**Penetration function formula:**

$$pen_{t,v,y} = maxpen_{t,v} - \frac{1}{\frac{1}{maxpen_{t,v}} \cdot e^{[\alpha \cdot (y-1990-9-simplepayback_{t,v})]}} \quad (\text{B - 147})$$

**Outputs to main commercial model and NEMS:**

units<sub>y,r,t</sub> – accumulated total units employing the relevant type of generation technology by Census division:

$$units_{y,r,t} = units_{y,r,t-1} + \left\{ \begin{aligned} & \left[ pen_{y,b,t} \cdot CMNewFloorSpace_{y,b,r} \cdot 1000 / avgsqft_b \right] + \\ & \left[ exogpen_{y,t} - exogpen_{y-1,t} \right] \cdot bldshr_{t,b} + \\ & \left[ deltapen_{y,r,t} \cdot CMSurvFloorSpace_{y,b,r} \cdot 1000 / avgsqft_b \right] \end{aligned} \right\} \quad (\text{B - 148})$$

where deltapen is the maximum of 1) the current penetration into new construction and 2) 0.25%.

trills (year, Census division, technology) – total kWh (own use and grid sales) generation (converted to trills).

trillsownuse (year, Census division, technology) – own use electricity generation. The minimum of 1) the average electric consumption (in trills) of the relevant building type, or 2) the actual kWh generation (converted to trills).

fuelusage (year, Census division, technology) – accumulator for fuelinput (see above)

hwbtu (year, Census division, technology) – accumulator for the variable waterhtgmmbtu (see above)

hwbtu

shbtu (year, Census division, technology) – accumulator for the variable spacehtgmmbtu (see above)

invest (year, Census division, technology) – current year investment in distributed generation resources in millions of 1998\$:

$$invest_{y,r,t} = \left( units_{y,r,t} - units_{y-1,r,t} \right) \cdot capcost_{t,v} \cdot kw_{t,v} / 1000000. \quad (\mathbf{B - 149})$$

# Appendix C

## 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., Characterization of Commercial Building Appliances, ADL reference 42520, prepared for U.S. Department of Energy, Office of Building Technologies, August 1993.

Arthur D. Little, Inc., Energy Savings Potential for Commercial Refrigeration Equipment, ADL reference 46230, prepared for U.S. Department of Energy, Office of Building Technologies, June 1996.

Arthur D. Little, Inc., "Technology Forecast Updates - Residential and Commercial Building Technologies," ADL reference 37125-00, prepared for U.S. Department of Energy, Energy Information Administration, September 1998.

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

Belzer, D., L. Wrench and T. Marsh, End-Use Energy Estimates for U.S. Commercial Buildings, 1989, Pacific Northwest Laboratory, PNL-8946, UC-350, November 1993.

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.

Data Resources Incorporated, U.S. Energy Model Technical Documentation, Lexington MA, November 1980.

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.

DRI-McGraw Hill, Compact Model of the U.S. Economy, Version US90A, Lexington MA, January 1991.

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.

Energy Information Administration, U.S. Department of Energy, 1995 Commercial Buildings Energy Consumption Survey, Public Use Data, Washington DC, October 1998, web site [www.eia.doe.gov/emeu/cbecs/](http://www.eia.doe.gov/emeu/cbecs/).

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, Annual Energy Outlook 1993, DOE/EIA-0383(93), Washington, DC, January 1993.

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, Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy, Washington DC, December 1990.

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, PC-AEO Forecasting Model for the Annual Energy Outlook 1990, Model Documentation, (Section 3, Commercial Energy Demand) and Technical Notes, DOE/EIA-MO36(90), Washington DC, March 1990.

Energy Information Administration, U.S. Department of Energy, State Energy Data Report: Consumption Estimates 1960-1989, DOE/EIA-0214(89), Washington DC, May 1991.

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

Gas Research Institute, Baseline Projection Data Book: GRI Baseline Projection of U.S. Energy Supply and Demand to 2010, 1992 edition, vol. I.

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.

Hirst, E. and R. Lee, "Independent Expert Review of the EIA Residential End-Use Model (REEM) and the Building Energy End-Use Model (BEEM)", Oak Ridge National Laboratory, June 1991.

Jackson, J. et al, The Commercial Demand for Energy: A Disaggregated Approach, Oak Ridge National Laboratory, April 1978.

Jerry Jackson and Associates, NPPC Commercial Energy Demand Model, Pacific Northwest Electric Power and Conservation Power Planning Council, Portland OR, November 1982.

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.

"Lighting the Commercial World," EPRI Journal, vol. 14, No. 8, December 1989.

Lowe, M., Shaping Cities: The Environmental and Human Dimensions, Worldwatch Paper 105, October 1991.

Mahoney, D., "Phase I of a Project to Enhance the Commercial Sector Analysis of the GRI Baseline Modeling System; Topical Report #1: Data Enhancements," prepared for Gas Research Institute under Contract No. 5085-800-1175, DRI Energy Division, Lexington MA, July 1987.

National Analysts, Synergic Resources Corp., QEI, Inc., Residential Customer Preference and Behavior: Market Segmentation Using CLASSIFY, EPRI EM-5908, Palo Alto CA: EPRI, March 1989.

National Economic Research Associates, NERA Energy Outlook, White Plains, New York, February 1993.

Piette, M., J. Eto, and J. Harris, "Office Equipment Energy Use and Trends," Energy and Environment Division, Lawrence Berkeley Laboratory, September 1991.

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.

Temple, Barker and Sloane, Inc., Xenergy, Inc., Market Research on Demand-Side Management Programs, EPRI EM-5252, Palo Alto CA: EPRI, June 1987.

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

U.S. Department of Energy, Office of Coal and Electricity Policy, Emerging Issues in PURPA Implementation, DOE/PE-70404-H1, Pfeffer, Lindsay, and Assoc., Inc, March 1986.

U.S. Environmental Protection Agency, "Green Lights Financing Directory Database," Version 2.0, January 1992.

"Utility Rebate Guide," Energy User News, Vol. 17, No. 4, April 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.

Westley, G., "The Demand for Electricity in Latin America," Inter-American Development Bank Papers on Project Analysis No. 35, Economic and Social Development Department, Country Studies Division, Washington, D.C., February 1989.

Z, Inc., TPL Codebook for 1986 Consumption and Expenditures Tables, NBECS 86, Z, Inc., Contract No. DE-AC01-85E119693, Silver Spring MD, April 1989.

[This page intentionally left blank]

## Appendix D. Model Abstract

### 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 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 cogeneration 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 integrated forecasting tool, the NEMS Commercial Module generates mid-term forecasts 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:

October 2000.

## **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:**

Erin Boedecker  
Office of Integrated Analysis and Forecasting  
Demand and Integration Division  
Energy Information Administration  
United States Department of Energy, James Forrestal Building  
1000 Independence Avenue, S.W.  
Washington, D.C. 20585  
(202) 586-4791

## **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(2001) (Washington, D.C., December, 2000).

## **Archive Media and Installation Manual(s):**

The Module will be archived on compact disk storage compatible with the PC multiprocessor computing platform upon completion of the NEMS production runs to generate the Annual Energy Outlook for 2001 (AEO2001).

## **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, 1990 through 2020
- 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 forecasted 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 forecast. Commercial Buildings Energy Consumption Survey 1995 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 model 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 nonbuilding consumption to benchmark
- Historical commercial sector quantities of cogenerated electricity by Census division, generating fuel, and building type
- Annual consumption of fuels for cogeneration 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.
- Forecasted commercial sector renewable energy demand, by renewable source and energy service

### **Non-DOE Input Sources:**

Data Resources Inc. (DRI), F.W. Dodge

- Commercial sector floorspace growth by Census division and building type
- Description of floorspace categorization to enable mapping to DOE sources

Arthur D. Little Technical Reports, EPRI Technical Assessment Guide, GRI Baseline Data Book (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 1990-1998
- Equipment research and development (R&D) advances and projected dates of model introduction, projections for technology availability encompassing the years 1999-2015

### **DOE Input Sources:**

Commercial Building Energy Consumption Survey 1995 (CBECS 1995)

- 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 nonbuilding consumption to benchmark

Form EI-860B: Annual Electric Generator Report - Nonutility, forms for years 1995-1998

- Historical commercial sector quantities of cogenerated electricity by Census division, generating fuel, and building type
- Annual consumption of fuels for cogeneration by Census division and building type
- Current status of commercial sector generating facilities

National Renewable Energy Laboratory (NREL) Interlaboratory Documentation, 1990

- Forecasted commercial sector renewable energy demand, by renewable source and energy service

### **Computing Environment:**

- Hardware Used: Compaq Proliant Multiprocessor Server
- Operating System: Windows NT with MKS Toolkit UNIX emulation
- Language/Software Used: FORTRAN
- Memory Requirement: 4,000K
- Storage Requirement: Model has not yet been archived. It will require an as-yet undetermined amount of space on compact disk
- Estimated Run Time: 1.28 minutes for a 1990-2020 run in non-iterating NEMS mode on an IBM RS/6000
- 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.

[This page intentionally left blank]

# Appendix E. Data Quality

## Introduction

The NEMS Commercial Sector Demand Module develops forecasts 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 1995 (CBECS 1995)***

EIA's Commercial Buildings Energy Consumption Survey 1995 (CBECS 1995) is the principal data source for the NEMS Commercial Module forecast of energy consumption. This section discusses the quality of the CBECS 1995 data set as described in *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures 1995*<sup>1</sup>.

***CBECS 1995 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 described in *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures 1995*.

The CBECS methodology consists of two major 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. 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

---

<sup>1</sup> U.S. Department of Energy, Energy Information Administration, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures 1995*, DOE/EIA-0625 (95), pp. 333-370.

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.

CBECS 1995 samples 8,074 buildings, selected based upon an area probability sample supplemented by lists of large buildings and special buildings. The source previously cited provides additional detail regarding the area probability sampling methodology. The sampling methodology relies upon the 1986 sampling methodology and includes some of the large and/or specialized commercial buildings previously sampled. Except for these few buildings, the 1995 sample does not overlap with previous CBECS. Primary differences between the CBECS 1995 sampling method and the CBECS 1986 sampling method are further described in the report previously cited.

***Building Characteristics Survey (Stage I)***. Target Population. The target population of CBECS 1995 is domestic commercial buildings greater than 1,000 ft<sup>2</sup> in area. All buildings in the sample satisfy three criteria: 1.) each meets the survey definition of a "building", 2.) each is used primarily for commercial purposes, and 3.) each measures 1,001 ft<sup>2</sup> or more. As described in the report previously cited, building eligibility is evaluated at multiple points throughout the survey purpose to ensure data accuracy and quality.

**Response Rates.** The total sample of CBECS 1995 is 8,074 buildings, composed of 6,633 from the area sample frame and 1,441 from the list sample frame. Of these, 6,590 buildings were found eligible for interviewing. Successful interviews for 87.5% of the eligible buildings (5,766) are contained in CBECS 1995, 4,728 from the area sample and 1,038 from the supplemental list sample. Of the 5,668 sample buildings reporting some energy use, 92.6 percent, or 5,250, submitted an Authorization Form to release confidential energy consumption data..

**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. A description of the CAPI techniques used is provided in the report previously cited.

**The Interview Process.** Each interview contains screening questions to verify building eligibility, followed by the survey questions. 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, the definition of a building, finding the sampled building, computer use and interviewing by CAPI, specific review of the questionnaire, and administrative information. This information is supplemented by general information on interviewing techniques for new interviewers. Trainee performance is monitored and evaluated by

supervisory personnel throughout the performance period and only those judged qualified contribute to the survey.

Random sample validation of 10% of respondents was accomplished by supervisory personnel in addition to the built-in edits and error checks provided by the CAPI system. These edits check for completeness and logical consistency, identifying cases with missing data. Key data items are pursued through telephone data retrieval procedures. Additional detail on these procedures is provided in the report previously cited.

***Energy Suppliers Survey (Stage II).*** Target Population. Each supplier of electricity, natural gas, fuel oil, district steam, hot water, and chilled water to a sampled building, provides consumption and expenditures data on a mailed survey form for this stage of CBECS 1995. The survey forms request data summed across several customers, either within a building or across a group of buildings, depending on whether individual building or district services are supplied.

**Response Rates.** The overall response rate for the Stage II survey is 84.9%. Each record obtained from this survey corresponds to a single energy supplier for a particular energy source to a particular building.

**Data Collection.** Prenotification through a mailed letter to natural gas and electric suppliers that were previous CBECS participants is one facet of the data collection effort. This form explained the CBECS survey and requested a contact person be designated for the 1995 survey. Prenotification was followed by mailed survey forms to energy suppliers based upon Stage I response patterns from the Building Characteristics Survey. Extensive efforts were used to obtain usable energy supplier data as described in the previously cited report..

**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 CBECS 1995 input data, which is the principal source of initial floorspace levels and age cohorts, appliance stock composition, district service shares, and unbenchmarked

1995 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 CBECS 1995 Public Use Data. The data are Statistically Adjusted Engineering (SAE) estimates based upon survey data collected in CBECS 1995 and building energy simulations provided by the Facility Energy Decision Screening (FEDS) system. The methodology used to obtain the final end-use estimates and data quality issues are addressed in *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures 1995*.

### ***Technology Characterization Data Sources***

The EPRI, Arthur D. Little, 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), 1997***

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<sup>2</sup> 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 time preference premium segments and three behavior rules described in the body of this report. The time preference premiums are developed based on

---

<sup>2</sup> U.S. Department of Energy, Energy Information Administration, *State Energy Data Report 1997, Consumption Estimates*, DOE/EIA-0214(97), September 1999, pp. 335-444.

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 create 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.

### ***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 time preference interest rate premiums and averaged to yield a time preference premium distribution that is used in the NEMS Commercial Module.

Insufficient data were available to disaggregate consumer discount rates by Census division or by technology (i.e., the sample size was too small). As documented in the published data sources, the variance of each estimate was far greater than the difference between the studies by technology or region. Therefore, a single distribution is applied to all technologies and all Census divisions.

The five distributions of commercial sector payback requirements from the literature were first converted to discount rates assuming mid-year cash flows and 30 year lives. 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. The resulting average commercial consumer time preference premium distribution is:

**Table E-1. Consumer 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. 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. This shift represents the effects of the voluntary programs such as Green Lights, an initiative of the Climate Change Action Plan.

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. 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. 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	- or $\infty$

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, p. 16.

**Table E-3. Commercial Consumer Payback Requirement Distributions**

Payback Period (years)	Cumulative Percent of Consumers with Payback Requirement			
	Con Ed	SCE	[proprietary]	EIA
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.

**Behavior Rule Proportions: Supporting Documentation**

**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 %
<b>TOTAL:</b>	<b>20.5 %</b>	<b>63.0 %</b>	<b>16.5 %</b>

## 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 1997, Consumption Estimates*, DOE/EIA-0214(97), September 1999.
- Vine, E. and J. Harris, "Implementing Energy Conservation Programs for New Residential and Commercial Buildings," *Energy Systems and Policy*, Vol. 13, No. 2, 1989.