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

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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 1995*.

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1. Introduction

Purpose of this Report

This report documents the objectives, analytical approach and development of the National Energy Modeling System (NEMS) 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 statistical and forecast reports (*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 Demand Module serves two purposes. First, it generates 1990-2010 forecasts of commercial sector energy demand as a component of the NEMS integrated forecasting system. Second, it facilitates policy analysis of energy markets, technological development, environmental issues and regulatory development as they affect commercial sector energy demand.

The NEMS system requirements for the Commercial Sector Model are straightforward. In order to integrate with the NEMS energy supply models, it must generate fuel consumption forecasts for electricity, natural gas, and distillate fuel oil.[1] These forecasts are based on energy prices and macroeconomic variables from the NEMS system, combined with external data sources.[2]

The NEMS Commercial Sector Model must be relevant to the analysis of current and proposed legislation, private sector initiatives and technological developments.[3] 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

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[1]The End-Use Consumption Module (Chapter 2.4) 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.

[2]Energy Information Administration, U.S. Department of Energy, Model Documentation Report for the Annual Energy Outlook 1992, DOE/EIA, Washington DC, December 1991, pp. III-9,10.

[3]Hirst, Eric and Russell 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, pp. 2-4.

Archival Media

As of this writing, the model has not been officially archived. The model will be archived on IBM 3090 mainframe magnetic tape storage as part of the National Energy Modeling System production runs used to generate the Annual Energy Outlook 1994.

Model Contact

Mohammad A. Adra
Office of Integrated Analysis and Forecasting
Energy Demand Analysis Branch
Telephone (202) 586-6580

NEMS Commercial Model Structure

The commercial sector encompasses business establishments that are not engaged in industrial or transportation activities. Commercial sector energy is consumed primarily within buildings.[4] 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 four basic steps. 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 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. Building and equipment choices made in previous time periods largely determine the floorspace and equipment in place in future time periods.

[4]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.

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

Energy Service Demand Forecast

Once the building inventory is projected, the model then develops a forecast of demand (energy out, measured in Btu out) for energy-consuming services within buildings. Consumers do not demand energy per se, but the services that energy provides.[5] The following nine 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
- Office Equipment
- Refrigeration
- 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

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

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 short-term price elasticity of demand estimates for the major fuels of electricity, natural gas, and distillate fuel. If the price of energy is constant from one year to the next, there is no price elasticity effect on service demand.

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 service demand:

- service demand in newly-constructed buildings (constructed in the current year of the forecast)

- service demand formerly met by retiring equipment (equipment that is at the end of its useful life and must be replaced)

- service demand formerly met by equipment at the end of its <u>economic</u> life (equipment with a remaining useful life that is nevertheless retired 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, there is empirical evidence that suggests that traditional cost minimizing models do not adequately account for the full range of economic factors that influence consumer behavior.[6] Using a similar methodology, the NEMS Commercial Model 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 and retiring equipment, but minimizes costs under that constraint, and
- Buy (or keep) the same technology as the existing and retiring equipment, but choices between different efficiency levels are still 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 on the share of consumers using each behavior rule. The proportions of consumers in each segment vary by

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[6]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, <u>Building Energy Efficiency</u>, OTA-E-518, Washington DC: U.S. Government Printing Office, May 1992, pp. 73-85.

building type and decision type, for the three decision types of new construction, replacement of worn-out equipment, or retrofitting of "economically obsolete" equipment[7]

The model is designed to choose among a discrete set of technologies that are exogenously characterized by commercial availability, capital costs, operating and maintenance (O&M) 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 technology choices, recognizing that changes in energy prices and consumer demand may significantly change the set of relevant technologies which the model user wishes to consider.

Energy Consumption

Following the choice of equipment to satisfy service demands, the model must then compute the total amount of energy consumed. To calculate energy consumption, the equipment share for each fuel and its corresponding efficiency is applied to service demand. An example of this calculation is shown in **Table 1.** If 500 MMBtu of heating service demand in new office buildings in the Northeast is required, then the calculations are as follows:

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7 Additional detail regarding the derivation of the choice proportions is provided in Appendix A to this report, first referenced in Table A-1, p. A-3.

TABLE 1. ENERGY CONSUMPTION CALCULATION

Service Demand 500 MMBtu		Average efficiency (Btu out/ Btu consumed) (3)	Fuel Consumption (MMBtu) (4) = (2)/(3)
Fuel (1)	Proportion of Service Demand (2)		
Distillate Fuel Oil	0.5	0.75	333.3
Electricity	0.3	0.87	172.4
Natural Gas	0.2	0.80	125.0
Total			630.7

- Allocate service demand according to the share of a given fuel (**Table 1**, Column 4)
- Divide service demand (2) by the average efficiency (3) to derive fuel consumption by fuel type.

Forecasted building energy consumption is then benchmarked to the State Energy Data System (SEDS) historical commercial sector consumption, applying a multiplicative factor 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-off point for the forecast. The benchmarking procedure is further discussed in the last section of the maintext of Volume I of this report.

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 mainframe. 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 model equations and variable transformations. Appendix C is a bibliography of reference materials used in the development process. Appendix D consists of a model abstract, and Appendix E discusses data quality and estimation methods.

Volume II of this report discusses the mathematical properties of the NEMS Commercial Module and also provides sensitivity analysis and scenario output in support of the documentation of model performance.

2. Model Purpose

Model Objectives

As discussed in Section 1 of this report, the NEMS Commercial Sector Module serves two objectives. First, it develops mid-term forecasts of commercial sector energy demand, currently spanning a forecast horizon of twenty (20) years, from 1990 to 2010, as a component of the NEMS integrated forecasting system. 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. Each of these objectives is discussed in greater detail in the following paragraphs.

As a component of NEMS, the commercial model provides sectoral fuel consumption forecasts to be used by other NEMS modules. Specifically, the demand forecasts produced by the Commercial Module are utilized in conjunction with other projected sectoral demands as inputs to the corresponding NEMS energy supply modules. The NEMS supply modules determine the composition of sources and resulting amount of energy delivered to each sector based upon available resources and sectoral demands.

Of equal importance, the Commercial Module is also a useful policy tool. The flexible model design is able to accommodate a wide range of scenario developments. Both the input file structure and the model source code have been developed to facilitate "what if" analysis of energy markets, technology characterizations, market initiatives, environmental concerns, and regulatory policies such as demand-side management (DSM) programs.

Model Input and Output

This subsection summarizes the primary features of the model input and output. It addresses the issue of developing and interpreting scenarios using the Commercial Module within the NEMS Integrated System, providing insight into the specific model mechanisms employed.

Emphasis is placed on the interrelationships of modeled variables, particularly the ultimate effects upon energy consumption of input "driver" variables. While examples of how to make minor modifications to the processes and input files are included, major changes to the code, data structures, or auxiliary files are beyond the scope of this subsection.

As the Commercial Module resides on the Energy Information Administration's (EIA's) IBM 3090 mainframe, and is accessed through the SuperWylbur interface, prior experience with these environments is presumed. Documentation for SuperWylbur can be obtained through the PRINTMAN macro member of &PUBLIC.MACROS.

Structural Overview

The NEMS Commercial Module is a sequential structured program. That is, a series of subroutines is called in sequence, each producing results that depend on results generated by the subroutines called previously. For each year of the forecast period, the processing flow proceeds roughly as follows:

1. A forecast of commercial building floorspace is generated based upon input from the Macroeconomic Module. (COMFloorspace subroutine).

2. Demands for various services are calculated for that floorspace (COMServiceDemand subroutine).

3. Equipment is chosen to satisfy the demands for services (COMTechnologyChoice subroutine).

4. Fuel consumption is calculated based on the chosen equipment mix, and additional commercial sector consumption components such as cogenerated electricity and commercial sector airborne emissions are calculated (COMConsumption subroutine).

5. Results by fuel and Census Division are adjusted to match the 1990 State Energy Data System (SEDS) historical data (COMBenchmarking subroutine).

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.

A final reporting subroutine, COMReport, generates detailed documentation on the Final Control and Reporting Loop of the last forecast year.

Variable Classification

Model 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 generally represented by the following notation:

CENSUS DIVISION

Subscript (r)	Refers to
1	New England
2	Middle Atlantic
3	East North Central

4	West North Central
5	South Atlantic
6	East South Central
7	West South Central
8	Mountain
9	Pacific

BUILDING TYPE

Subscript (b)	Refers to
1	Assembly
2	Education
3	Food Sales
4	Food Service
5	Health Care
6	Lodging
7	Office -- Large
8	Office -- Small
9	Merc/Service
10	Warehouse
11	Other

SERVICE

Subscript (s)	Refers to	
1	Space Heating	(Major)
2	Space Cooling	(Major)
3	Hot Water Heating	(Major)
4	Ventilation	(Major)

5	Cooking	(Major)
6	Lighting	(Major)
7	Office Equipment	(Minor)
8	Refrigeration	(Minor)
9	Other	(Minor)

The Major end-uses listed above are modeled in the Technology Choice Submodule described in the Model Structure section of this report. Minor end-uses are forecast using equipment efficiency and market penetration trends.

FUEL

Subscript (f)	Refers to	
1	Electricity	(Major)
2	Natural Gas	(Major)
3	Distillate	(Major)
4	Residual	(Minor)
5	LPG	(Minor)
6	Steam Coal	(Minor)
7	Motor Gasoline	(Minor)
8	Kerosene	(Minor)
9	Wood	(Renew)
10	MSW	(Renew)

Forecasted energy demand for the Major fuels listed above takes into account the price elasticity of service demand as described in Equation 17 below. Minor fuel demands do not incorporate price elasticity of demand impacts.

EQUIPMENT TECHNOLOGY CLASS, EQUIPMENT VINTAGE

Subscripts (t,v) — Refer to

Representative piece of equipment within a technology class (t) is available in one or more models (v) for competition in Technology Choice Submodule. The current Technology Choice Submodule allows for a maximum of 7 vintages for each piece of representative equipment. An example of two different vintages for the same technology class would be: 1) an electric resistance hot 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.

CONSUMER TIME PREFERENCE PREMIUM SEGMENT

Subscript (p) — Refers to

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 eleven (11) consumer time preference premiums to characterize the commercial consumer decisionmaking population.

Subroutine Process Description

COMFloorspace. Many of the parameter estimates used in the Commercial Module, including base year (1989) commercial sector floorspace, are developed from the 1989 Commercial Building Energy Consumption Survey (CBECS) data base. Forecasted total commercial floorspace is provided by the NEMS U.S. Macroeconomic Activity Module (MAM) through the MC_COMMFLSP member of the NEMS Global Data Structure (GDS). Commercial floorspace from the MAM is provided by the 14 building categories forecast by Data Resources Incorporated

(DRI).

Data from the CBECS and DRI sources are combined in order to provide the year-to-year forecast of surviving and new commercial building floorspace by CBECS building category.

New additions to the stock of commercial floorspace forecast for each year are derived from the MAM forecast (based on the DRI forecast) as follows:

1. Floorspace retirement rates assumed by the DRI model are input from file KDRI and used to calculate the amount of floorspace for each DRI building type that implicitly survives from the prior year into the current year.

2. The surviving floorspace obtained in the previous step is subtracted from the total DRI floorspace forecast for the current year to obtain the new floorspace for each DRI building type.

3. New additions to floorspace for each DRI building type obtained in the previous step are mapped to the CBECS building types, completing the forecast of new floorspace.

Surviving floorspace from previous years depends on both the composition of the base year (1989) CBECS stock and all new floorspace added between 1989 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 model 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 average year of construction for each vintage range is input from file KVINT. These values also vary with building type and Census Division.

3. Key building survival parameters are input from file KBLDG. These include the average lifetime for each building type, and a shape parameter (gamma) that characterizes the shape of the logistic function used to represent the surviving proportion of original floorspace as a function of time, for each building type.

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. This time series of new floorspace is spliced to the new floorspace obtained from the DRI forecast to produce a total history of new additions to floorspace, starting with the original stock of the oldest CBECS vintage. 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.

COMServiceDemand. The model partitions energy-consuming activities in the commercial sector into nine services. These are:

1	Space Heating	(Major)
2	Space Cooling	(Major)
3	Hot Water Heating	(Major)
4	Ventilation	(Major)
5	Cooking	(Major)
6	Lighting	(Major)
7	Office Equipment	(Minor)
8	Refrigeration	(Minor)

9 Other (Minor)

Services are further subdivided into major and minor categories. For major services, the model forecasts the evolving market shares of the equipment mix providing those services in the Technology Choice subroutine, and uses these shares to calculate average efficiencies and fuel shares. Minor service consumption is projected using exogenous forecasts of average efficiency and fuel shares. Because of this and other differences, treatment of these two categories of service are discussed separately below.

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 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.

Service Demand Intensity (SDI), defined as the service demand for a service per square foot of floorspace, is assumed constant for each service. 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.

Major Services. SDIs for space heating, space cooling, hot water heating, ventilation, and lighting are input from file KINTENS by building type and Census Division. SDIs are derived from the 1989 CBECS Energy Use Intensities (EUIs), which are the input Btu per square foot, through multiplication by the corresponding 1989 average efficiencies of the equipment stock providing those services.

In order to obtain service demand for each major service in each building type and Census Division, for both existing and new floorspace, SDI is multiplied by the corresponding floorspace forecast. Space conditioning services are also multiplied by a shell efficiency index normalized to 1989 building shell efficiencies for existing and new buildings. The market for the largest major services is assumed to be saturated; the model assumes no increase in market penetration in existing floorspace for the services of space conditioning, water heating, and lighting.

Minor Services. Forecasts of end-use consumption for office equipment, refrigeration, and "other" services are developed without the intermediate step of calculating service demands and equipment choices. The methodology is as follows:

First, minor service EUIs are input from the file KINTENS. The efficiency of the existing stock of minor service equipment is calculated as an index, beginning with a value of 1.00 for the 1989 existing stock. Therefore, the product of the base year EUIs and the 1989 efficiency of 1.00, which is the SDI, is the same as the EUI value for the base year.

Service demand by building type, Census Division, and floorspace vintage (new construction and existing stock), is computed analogously to major services, with two important differences:

1. Building shell efficiency indices are not applicable.

2. A market penetration index for office equipment developed using an exogenous forecast of market penetration is input from file KOFFPEN and multiplied by the SDI and floorspace product during the calculation of service demand for office equipment.

Other differences in treatment between major and minor services arise in the subsequent calculations of average efficiencies and fuel shares, described in the COMTechnologyChoice section below.

Enhancements to Calculated Base Service Demand. Calculated service demands are subject to modification by several relevant commercial sector considerations. District services (space heating, space cooling, and water heating) are one such consideration. A proportion of these services that varies with building type and Census Division is satisfied by district services. The previously-obtained raw service demand figures are decremented by these proportions.

Another factor that reduces the service demands that must otherwise be satisfied by technology choices is the direct use of solar energy for space heating, water heating, and lighting. A forecast of such use, compiled by the National Renewable Energy Laboratory (NREL), is input from file KRENEW. KRENEW provides annual consumption amounts that are subtracted from service demands net of district services.

The short-run price elasticity of demand for the remaining service demands is treated in some detail. Price elasticity is computed using one-year (prior year to current year) changes in fuel prices, and captures such effects as resetting of thermostats when heating or cooling technology fuel prices change.

1991 is the first year to be impacted by price elasticity of service demand, since the model is benchmarked to SEDS 1990 historical data. Short run price elasticities of service demand for each service and fuel type are input from file KSDELA. Based on year-to-year price changes calculated from the NEMS price series, service demand elasticities are computed for each fuel type and service. Finally, the fuel-specific service demand elasticities are weighted by the calculated fuel shares for each service considered, resulting in a composite service demand elasticity that is applied to yield the modified service demand.

Computed service demands in existing floorspace are apportioned into two distinct categories for separate processing by the Technology Choice subroutine:

1. Service demand met by equipment in need of replacement (replacement service demand);

2. Service demand met by equipment still in service, but which is candidate for retrofitting due to economic considerations (retrofit service demand).

Currently, a simplifying assumption based on the average range of equipment lifetimes of twenty (20) years, 5%, or 1/20 of the existing stock, of the service demand in existing floorspace is considered candidate for equipment replacement, with the remainder subject to the retrofit decision. Future enhancements to this simplifying assumption include considering the distribution of existing equipment vintages in service for each original year of purchase in order to calculate the proportion in need of replacement.

COMTechnologyChoice. The Technology Choice (Tech Choice) subroutine forecasts equipment selections with which service demands of the major services are met. Tech Choice then computes average efficiencies and fuel shares of the resulting equipment mix which in turn are used in the COMConsumption subroutine to calculate fuel consumptions. Average efficiencies and fuel shares for minor services are also updated within this subroutine.

The model currently employs a technology characterization data base that encapsulates all pertinent commercial sector technology data in a highly flexible format. The data base facilitates simple and rapid modification in support of alternative scenario analyses, and resides in the mainframe file KTECH. KTECH is transferred to internal storage during the first pass through subroutine COMTechnologyChoice. Representative equipment is identified in the data base with a technology index subsequently used in COMTechnologyChoice, as well as a vintage (technology class model) index, the index of the fuel it consumes, the index of the service it provides, its initial market share, the Census Division index for which the entry under consideration applies, its efficiency (or COP; efficacy in the case of lighting equipment), installed capital cost per unit of service demand satisfied, operating and maintenance cost per unit of service demand satisfied, average lifetime, year of initial availability, and last year available for purchase.

Equipment may only be selected to satisfy service demand if the year in which the decision is made corresponds to the time in which the equipment is available in the marketplace as defined in KTECH. However, equipment acquired prior to the lapse of its availability continues to be treated as part of the existing stock, and is subject to replacement or retrofitting. This flexibility in phasing equipment in and out supports alternative standards specification. It also makes possible research into the potential market success of new improved equipment models.

COMTechnologyChoice selects equipment based on three distinct decision types:

1. *New* - select equipment to satisfy service demands in new floorspace.

2. *Replacement* - select equipment to satisfy service demands previously satisfied in existing floorspace by equipment that is in need of replacement in the current year.

3. *Retrofit* - select equipment to satisfy all service demands not included in either of the two categories described above. This decision type considers all equipment not in need of replacement or installation in new floorspace to be candidates for retrofitting with alternative equipment for economic reasons, subject to certain behavioral constraints as described below.

Consumer Behavior. The decision-making process applied to technology acquisition is characterized by commercial consumer behavioral rules and explicit time preference (discounting) premiums.

Three behavior rules are modeled:

1. *Least Cost* - guides consumers to compare all costs of all equipment available for satisfying the desired service, and to select that equipment associated with the smallest total annualized cost.

2. *Same Fuel* - as with the Least Cost rule, consumers compare all costs of available equipment satisfying the desired service and choose the least expensive; however, for the Same Fuel rule, this consideration is restricted to equipment using the same fuel as was previously used. The quantity of equipment previously using each fuel is characterized by the previous year's fuel shares for that service.

3. *Same Technology* - as with the Same Fuel rule, the menu of equipment considered for purchase based on cost is restricted; in this case, to equipment belonging to the same category of technology as was previously used. For purchases to satisfy New or replacement service demand, this rule permits acquisition of higher or lower efficiency models of the technology, whereas for the Retrofit case, it represents the decision to retain existing equipment.

Behavior rules are specified as the proportions of consumers making each of the Decision Types that follow each of the described behaviors. The values are input from file KBEHAV, and are based upon quantitative processing of literature sources pertinent to both residential sector and commercial sector decisionmakers. The analysis considers such factors as building ownership characteristics, including government and private ownership patterns, speculative building vs. own-use construction, and risk-taking patterns.

Technology Costs. The costs considered for each behavior rule consist of both actual costs and perceived time preference premium components. All new equipment costs are in units of dollars per unit service demand per hour, and are annualized over the lifetime of the equipment. These include:

1. Annualized Capital Cost (ACC)
2. Operating and Maintenance Cost (OMC)
3. Fuel Cost (AFC)

ACC represents the annualized initial cost of purchasing and installing the equipment. It is a function of the equipment's unit installed capital cost (input from KTECH), the equipment's capacity factor (input from KCAPFAC), and the ten year Treasury bond interest rate (obtained from the U.S. Macroeconomic Module). It is also influenced by both the consumer's perceived time value of capital (discussed in further detail in this subsection) and an implicit factor that represents auxiliary costs associated with such activities as converting the infrastructure to support distillate equipment.

Fuel costs are based on equipment efficiencies and price expectations over the lifetimes of the equipment, and as such, depend on the foresight routine employed (i.e., myopic, adaptive, or perfect foresight).

The consumer's perceived time value of capital is modeled using a distribution of eleven consumer time preference interest rate premiums, input from file KPREM. Each time preference premium category is associated with the proportion of consumers (as assessed through quantitative assessment of literature sources as described above) who view the time value of capital as associated with that premium. In computing the base cost of capital, the ten year Treasury Bond rate is increased by the time preference premium. In all cases, the annualized cost of capital is developed based on the specific equipment lifetime. As a result, the discounting is performed over varying horizons. For example, the ACC for a gas boiler may be computed based on a 20 year expected lifetime, compared to a 12 year expected lifetime for an electric heat pump.

Cost Comparisons. When selecting equipment to meet new and replacement service demand for a specific Census Division, building type, and service, cost tables are first constructed for each of the three behavior rules.

For the particular mix of technologies applicable to the service and behavior rule under consideration, the cost of each technology is computed as a function of each of the time preference premiums. Consumers in a given time preference premium category following a given behavior rule will all select one particular technology and model of equipment; namely, the equipment that appears least expensive from the vantage point of that particular time preference premium category under the constraint of that particular behavior rule.

For each applicable technology, the fraction of consumers in each of the time preference premium categories that selected that technology is summed to give the fraction of consumers following the given behavior rule that selected the given technology, recognizing that other technologies are available, so these fractions will not sum to unity. Finally, this figure is multiplied by the proportion of consumers that follow the given behavior rule in making the given decision type, resulting in the market share of the given equipment within the given decision type.

A similar calculation is performed for selections within the retrofit decision type, except that cost comparisons must be made not only between equipment alternatives available for purchase, but must also be relative to the costs of retaining existing equipment. This requires an additional cost table containing the Annualized Cost of Existing Equipment (ACE), to be constructed. This table is developed as described previously, but the capital cost component is considered to represent sunk costs, and is therefore set to zero. This has the effect of removing the dependence of this table on the time preference premiums.

Equipment selections are processed for each of the three behavior rules as in the new and replacement decision types described above, but in this case the existing equipment is also considered in the comparison. In addition, consumers possessing a given type of existing equipment will in general choose a variety of equipment with which to retrofit, in accordance with their particular time preference premium category. This calculation is required in order to model not only the proportion of consumers in each premium category that selects a given type of equipment, but also the market share of the original equipment from which that proportion switched. These figures are multiplied, and the product is summed across all applicable original equipment to yield the new equipment market shares within each of the behavioral segments of each decision type. Note that for the Same Technology behavior segment, this results in behavior segment market shares equal to the previous year's aggregate market shares within the particular Census Division, building type, and service being considered. As in the new and replacement cases, the equipment shares within each behavior rule segment are multiplied by the behavior rule proportion of the decision type to yield the equipment market shares within the retrofit decision type.

Fuel Shares, Average Efficiencies, and Consolidation of Output for Reporting. Fuel shares and average technology efficiencies within decision types are calculated from the market shares of equipment within each Census Division, building type, major service, and decision type, and are combined with information derived from KTECH for equipment efficiency and fuel. The calculated fuel share is simply the sum of market shares of equipment using the given fuel, and the average efficiency is the reciprocal of the summed ratios of equipment market share to equipment efficiency.

These results are aggregated across decision types, resulting in fuel shares of service and average efficiency by Census Division, building type, major service, and fuel type; and equipment market shares of service by Census Division, building type, major service, technology, and model. Similar aggregations are performed to obtain additional results across building types and Census Divisions.

Minor Services. Average efficiencies and fuel shares are determined for the minor services in a different manner. An exogenous forecast of the efficiency improvement for each minor service is input from file KDELEFF. The percentage improvement is multiplied by the previous year's value of the average equipment efficiency. Since all of the minor services use only electricity, fuel shares for these services are set to all-electric.

DSM Linkage. Market shares of service demand met by each available technology class within each building type, decision type, service, and Census Division are communicated to the NEMS Load and Demand-Side Management Module (LDSM) of the Electricity Market Module (EMM) each year of the forecast. In addition, if a "frozen forecast" in a special DSM binary file is requested by LDSM, this information, along with total electric consumption by Census Division, is written to the file.

COMConsumption. Consumption forecasts by major fuel, building type, service, and Census Division are composed of the product of corresponding service demands and fuel shares, dividing by calculated average equipment efficiency. Lighting consumption must then be converted from lumen-based units (since lighting technology characterizations are commonly represented in lumens) to obtain energy units consistent with the other services (trillions of Btus). The result constitutes the unbenchmarked consumption forecast.

Consumption of minor fuels is computed by Census Division, based upon trended historical values from 1990 SEDS. The annual forecasted growth rates for minor fuel consumptions vary by fuel and Census Division, and are input from the file KPARM.

Contribution from Cogeneration of Electricity. Historical data for electricity cogeneration as a function of Census Division, building type, and fuel for the calendar years 1990 and 1991 is input into the model from the files KCOG90 and KCOG91, respectively.

After 1991, a forecast of electricity cogeneration as disaggregated above is developed through a two-step process:

1. A baseline forecast is generated by multiplying previous year consumption by a growth factor that is based on historical data from EIA's form EI-867. The annual nonbuilding electricity growth factors that are used for benchmarking (discussed in the Benchmarking section of Chapter 4 of this report) are also used to generate the baseline cogeneration forecast. These factors are read from the file KCOGPRM.

2. The baseline forecast is modified to reflect the effects of cross-price elasticity between the generating fuel price and the price of electricity. Current year prices are normalized relative to the base case AEO93 price forecasts used to generate the growth factors. The AEO93 prices are used as a documented baseline forecast of energy prices in order to develop a price elasticity response. These prices are input from file KCOGPRC, and elasticities are input from file KCOGPRM. The cross-price elasticity effect is not considered for wood and MSW fuels.

For each year of the forecast period, all cogenerated electricity is assumed to be sold to the grid, and subsequently a portion is bought back to meet part of the consumption necessary to satisfy service demands.

As a result of using equipment to generate electricity in addition to satisfying service demands, more fuel is consumed than would be the case if cogeneration were not taking place. This is analogous to primary energy consumption. This incremental fuel consumption is calculated as follows:

1. Since the amount of cogenerated electricity produced by the cogenerating equipment is known, a measure of the amount of service demand simultaneously satisfied can be obtained. This is done by multiplying the cogenerated electricity quantity by the ratio of cogenerating

equipment thermal energy output to electricity produced in order to obtain the amount of thermal energy available for satisfying service demands. This calculation is performed each forecast year, by Census Division, building type and fuel. The ratio is a constant parameter input from file KCOGPRM.

2. The excess fuel consumed by the cogenerating equipment to produce the thermal energy described in step 1, over that which would have been consumed by comparable equipment if electricity were not being cogenerated, is calculated by multiplying the thermal energy by the difference in corresponding efficiency reciprocals. This difference is assumed constant and input from file KCOGPRM.

Incremental consumption of major and renewable fuels is added to consumption totals which are not service-specific (i.e., after consolidation across services).

Mapping of Results to the NEMS Global Data Structure

* All nonutility consumption of fuel for cogeneration is mapped to the NEMS Global Data Structure, as are electricity sales to the grid.
* Consumption results (from the basic consumption calculation, prior to consideration of cogeneration) are aggregated across building type and Census Division to produce U.S. consumption by fuel, service and year, and are mapped to the NEMS Forecast Tables (FTAB). This calculation occurs prior to the multiplicative benchmarking to SEDS. The FTAB table does not report the non-building, non-end-use specific consumption embodied in the SEDS benchmarking reconciliation, discussed in the following section of this report.
* Total consumption within each building type is calculated by adding consumption related to cogeneration to the unbenchmarked consumption forecast, and also adding the contribution made by solar thermal, then aggregating across service, fuel, and Census Division to obtain the FTAB entry titled, "Total U.S. Consumption by Building Type".

COMBenchmarking. Consumption of all fuels is benchmarked to SEDS. Because of the calculation methodology for minor fuels, based on growth of 1990 SEDS values, no additional benchmarking is required. Major fuel consumption is developed primarily from components derived from 1989 CBECS data, which differs notably from historical SEDS values for natural gas and distillate. The difference between the two reported data sources is resolved using 1990 Commercial Module consumption results and SEDS 1990 historical data through the following benchmarking procedure:

Unbenchmarked fuel consumption for 1990, including the contribution resulting from the cogeneration of electricity, is aggregated across services and building types to yield total consumption of each major fuel by Census Division. These figures are subtracted from the corresponding 1990 SEDS values to obtain the amount of the discrepancy. These discrepancies are the result of numerous differences between CBECS and SEDS data collection procedures.

The most significant component of the discrepancy in the data is attributable to non-building consumption of fuels by the commercial sector. Accordingly, the consumption levels represented by the discrepancy are expected to grow with time at the rates expected for non-building fuel use.

Unbenchmarked fuel consumption is then incremented by a component that includes a growth factor and represents non-building use, in such a way that the 1990 SEDS values are tied, and the non-building component grows linearly at average annual rates input from file KPARM as a function of fuel and Census Division.

Calculation of Environmental Emissions. After the consumption forecasts are determined, quantities of associated airborne pollutant emissions are calculated. A simple linear relationship is assumed, and is represented by emissions factors input from file KEMFAC. For each fuel, there is a separate emission factor corresponding to each pollutant considered. Resulting emissions are mapped for reporting in the NEMS FTAB.

Mapping Benchmarked Consumption to NEMS. The final substantive action taken by the Commercial Module in a given iteration of a forecast year is to map the forecasted demand for each fuel to the appropriate consumption arrays (the commercial portion of the NEMS "Q-Block") of the NEMS Global Data Structure. The final, benchmarked consumption projections by fuel are provided for both the supply modules and for reporting in the NEMS FTAB report. The NEMS system requires the final total demands, including the SEDS discrepancy. In contrast, the detail required for the FTAB Commercial Sector Supplementary Tables is specific to commercial building consumption and commercial end-use consumption, exclusive of the non-building and non-end-use specific consumption embodied in the SEDS reconciliation.

COMReport. Microdetailed results pertinent to internal testing and debugging of the Commercial Module are written to the output files KQUANT, KDEBUG, and KRPT.

Relationship of the Commercial Module to Other NEMS Modules

As described in previous sections of this report, 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 electricity prices from the EMM, the natural gas prices from the Natural Gas Supply Module, and the petroleum prices from the Petroleum Market Module (PMM) are primary drivers for the technology cost comparison, the forecast of commercial sector cogeneration, 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.
In summary, the primary inputs to the Commercial Module from the NEMS system are commercial floorspace forecasts and Treasury Bill interest rate forecasts received from MAM, and energy price forecasts received from the NEMS supply modules. The primary outputs of the Commercial Module are fuel consumption forecasts by Census Division, inverse average equipment efficiency by service, fuel and decision type, and fuel proportions of service demand by service, fuel and decision type.

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 sequential 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) will become operative market choices in the year 1993. This

1993. This is modeled in the data base by the elimination of noncompliant equipment choices and introduction of compliant equipment choices by the year 1993. 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 model run is assumed to be the floorspace stock published in CBECS 1989.

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 is assumed in each service to produce the CBECS 1989 energy consumption when the EUIs derived from the CBECS 1989 data are applied.

The model currently assumes a simplification of the equipment retirement function that sets annual equipment retirements to 5% of the existing equipment stock.

Service Demand Intensity (SDI) is assumed constant over the forecast period, 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 to preserve the SDI.

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, and lighting is modeled.

Technology Choice Submodule

As described in Section 2 of this report, 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-1, Appendix A to this report.

Also described in Section 2 of 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 to consumer behavior in order to quantify these concepts for inclusion in the model. Documentation of these assumptions is referenced in Table A-1 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 for minor services (office equipment, refrigeration, and "other" services) is forecast to increase over the forecast period based on published sources that are further referenced in Table A-1, Appendix A to this report. Minor services are 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.

Building Energy End-Use Model (BEEM): EIA

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

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

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

Floorspace. BEEM measures building stock by square footage of floorspace, for the seven building types and four Census Regions. Floorspace growth is composed of the combined effect of floorspace construction and attrition of existing stock. Base year floorspace is based on NBECS-86. This floorspace declines annually at constant attrition rates by region, while new floorspace is 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) is used as a proxy for the 1987 new construction pattern by building type. The 1987 estimate is then extrapolated annually by region, at the same rate of growth as regional employment growth. The module then computes total floorspace by adding existing and new floorspace by region and building type.

Service Demand. The service demand module tracks 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) is multiplied by corresponding floorspace. Energy efficiency of building shells improve over time relative to 1986 stock, reducing the demand for heating and cooling services. Thus, a shell efficiency index is used as an adjustment factor to capture the reduction in service demand. Service demand is also adjusted to account for renewable energy consumption. Renewable energy contributions are exogenously estimated for geothermal consumption, which reduces space cooling service demand, and solar and other renewables, which reduces heating service demand.

TABLE 2. BEEM AND NEMS COMMERCIAL MODELS: CONCEPTUAL TASKS

Conceptual Task	BEEM Methodology	NEMS Commercial Model Methodology
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 declines gradually over the forecast period and the characteristics of newer buildings become progressively more important in determining consumption levels as the older and more energy intensive buildings retire.

Service demand is adjusted for equipment efficiency, and expressed in terms of energy output requirements. The service capacity module determines how these requirements are met (capacity) and consequently how much energy will be consumed. In the model, retiring equipment reduces existing service capacity. Replacement capacity refers to equipment that must be purchased to replace retired equipment. Eventually, equipment reaches then end of its useful lifetime and must be replaced.

Technology Choice. Each year, equipment is chosen to meet new and replacement service demand. Equipment technology is chosen based on life-cycle cost criteria. The life-cycle cost for a technology is 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 is chosen. The life-cycle cost is indexed to 1986. A 1986 market share corresponds to each technology option. A logit choice definition of the market share strategy is based on initial technology shares, and a price sensitivity ($\gamma = -7$). Since the life-cycle costs are indexed to 1 in 1986, initial market shares are identical to the 1986 market shares. Therefore, the shares for each service add to 1. Market shares change over time, based on the effects of fuel prices on life-cycle cost relative to 1986. Since γ is negative, a higher or lower fuel price respectively decreases or increases the share a technology receives of the investment in new capacity.

The impact on life-cycle technology choice on energy consumption is 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 is met by equipment that has the same efficiency as the equipment stock in the previous year.

Benchmarking. Equipment energy consumption is then passed through a series of calibration adjustments. The difference between State Energy Data System (SEDS) fuel consumption and forecast consumption in 1988 is the SEDS difference. In 1991, the model forecast plus the 1988 SEDS difference adjusted by a building growth rate factor is compared to the 1991 Short-Term Energy Outlook (STEO) value, yielding a STEO adjustment factor. Final consumption is computed in two steps. First, the SEDS adjustment is added to the model results. Second, this total is 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, are 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 is 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 is modeled in BEEM, which does not disaggregate heterogeneous equipment that meets a given service.

Commercial End-Use Model (COMMEND): EPRI

EPRI developed the COMMEND model to forecast commercial sector energy demands by end-use.[8] 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:

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

where:

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

[8]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.

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

Conceptual Task	COMMEND Methodology	NEMS Commercial Model Methodology
Forecast floorspace additions	Choice of: ■ Flow Approach ■ Simultaneous Equation estimation using lagged dependent and exogenous macroeconomic variables ■ Proportional approach to one variable, e.g., employment	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 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, 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.

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,

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

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,

$$S_{f,s} = e_{f,s} \times a_{f,s} \times F \tag{3}$$

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,

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

where,

f(t) is surviving floorspace,

α, β 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.[9] 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.) . 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:

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

where,

a_f is the share of floorspace for fuel f

[9] 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.

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.

TABLE 4. ORNL AND NEMS COMMERCIAL MODELS: CONCEPTUAL TASKS

Conceptual Task	ORNL Methodology	NEMS Commercial Model Methodology
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.

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,

$$\begin{matrix} Payback \\ period \\ equip\ cost \end{matrix} = \begin{matrix} Equip \\ Cost \end{matrix} + \begin{matrix} Install \\ cost \end{matrix} + (Price_f \times EUI + \beta_{f,b}) \times \begin{matrix} Payback \\ req. \end{matrix} \qquad (6)$$

where the subscript f refers to fuel, and ß is a random variable with mean *b* and measure of dispersion

D.

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

$$U_t = U_{t-1} \times \left(1.0 + \frac{P_{f,t} - P_{f,t-1}}{P_{f,t}} \right) \times \begin{matrix} Utiliz \\ elast \end{matrix} \qquad (7)$$

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,

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

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

$$EUI = EUI_{t_0} \times Efficiencyindex \times Utilizationindex \qquad (9)$$

and t_0 refers to the base year of the forecast.

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,

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

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_{t0}	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

Conceptual Task	CEDMS Methodology	NEMS Commercial Model Methodology
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.

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

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.

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,

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

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.[10]

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,

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

where,

Y/X_t	is floorspace stocks over by a commercial output proxy (e.g. employment, taxable sales, etc.),.
PF/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,...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.

[10] This vintaging algorithm is a potential enhancement to the NEMS model that is currently under consideration.

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

$$\begin{matrix} \textit{Surviving Share} \\ \textit{of building vintage}_t \end{matrix} = \frac{1}{1 + e^{6.91 - 0.126 \cdot t}} \qquad \textbf{(13)}$$

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

Conceptual Task	CBEF Methodology	NEMS Commercial Model Methodology
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): EIA

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,

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

where,

- q is the price impacted energy intensity,
- p is the fuel price,
- p_{83} 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.

TABLE 8. CSEM AND NEMS COMMERCIAL MODELS: CONCEPTUAL TASKS

Conceptual Task	CSEM Methodology	NEMS Commercial Model Methodology
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 data on age and efficiency distribution of equipment stock
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

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.

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

BEEM

The BEEM floorspace forecast does not address variation of floorspace by Census Division and building type over time. The NEMS approach incorporates this consideration. The BEEM service demand algorithm is 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 is a simplified logit function that minimizes 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

CEDMS 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

Flow Diagrams

Figure 1 illustrates the general model flow of the current NEMS Commercial Sector Demand Module. The flow proceeds sequentially, first executing the Floorspace Submodule, followed by the Service Demand Submodule, then the Technology Choice Submodule, followed by the End-Use Consumption Submodule, which incorporates the benchmarking procedure.

As stated in Chapter 1 of this report, the model is a structured sequential program, and each succeeding Submodule utilizes 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 Floorspace Submodule requires the NEMS Macroeconomic Activity Module (MAM) 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 1989 and additional sources (further referenced in Table A-1 of Appendix A to this report) are also required for the execution of the Floorspace Submodule. The surviving and new floorspace results generated by the Floorspace Submodule, along with additional inputs including Energy Use Intensities (EUIs), renewable energy service demands, office equipment market penetrations, base year equipment stock efficiencies, equipment survival assumptions, and district service data, are required by the Service Demand Submodule.

The service demands produced by the Service Demand Submodule, combined with equipment-specific inputs, consumer time preference segmentation information specific to the Commercial

Module, and NEMS system outputs including Treasury Bill rates from MAM and fuel prices from the Electricity, Natural Gas, and Petroleum Supply Modules, are required by the Technology Choice Submodule. The average equipment efficiency and fuel proportions output by the Technology Choice Submodule are then input, along with cogeneration, environmental emissions, and benchmarking information, into the End-Use Consumption Submodule for processing.

Figure 1. Module Calculational Flow, p. 1

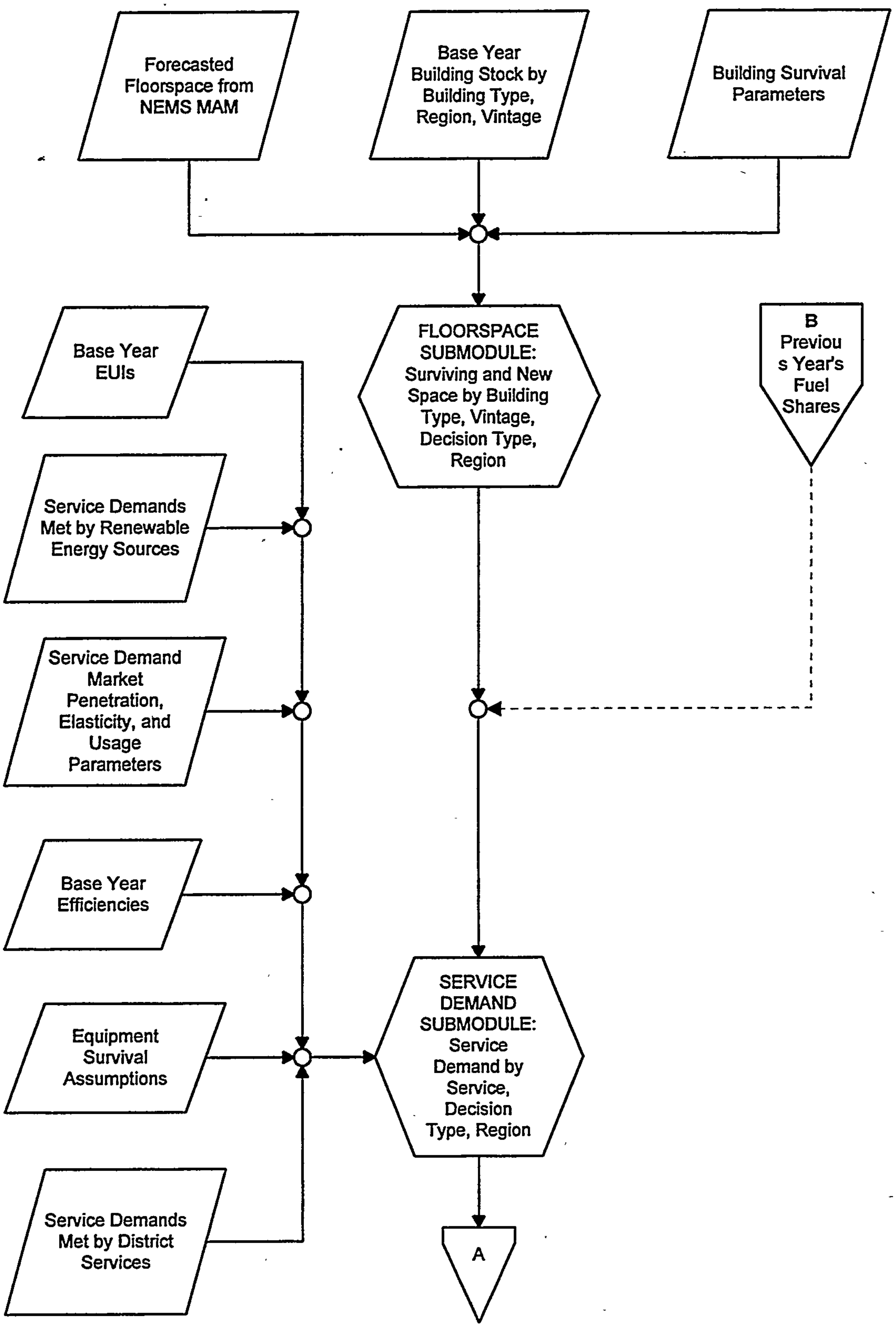
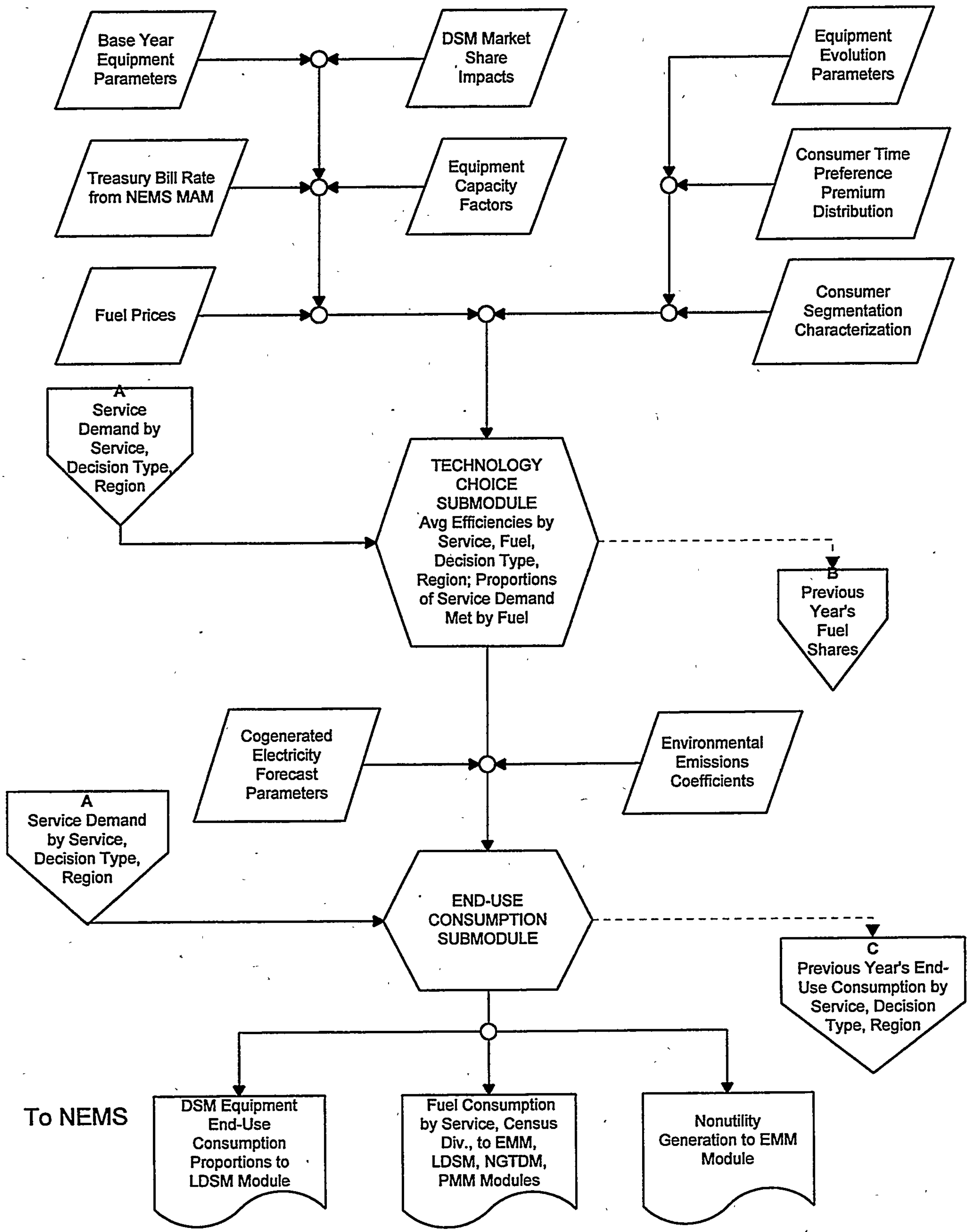


Figure 1. Module Calculational Flow, p. 2



Key Computations and Equations

This section provides detailed solution algorithms arranged by sequential submodule as executed in the NEMS Commercial Sector Demand Module. In general, the following conventions for subscript usage are observed in this section:

Subscript Designation	Description of Dimension Represented by Subscript
r	Census Division
b	NEMS Commercial Module building type
b′	NEMS MAM building type
s	End-use service
f	Fuel
d	Equipment decision type
t	Technology class
v	Vintage or model of floorspace or equipment, depending upon usage
p	Consumer time preference premium segment
y	Year designation (unless otherwise indicated, year ranges from 1990 through 2010)

Additional subscripts are defined when necessary. 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 variables appearing in the equations are cross-referenced and fully defined in Appendix A, Table A-1. Unless otherwise specified, the variables calculated in the NEMS Commercial Sector Demand Module are computed for the current year of the NEMS forecast only.

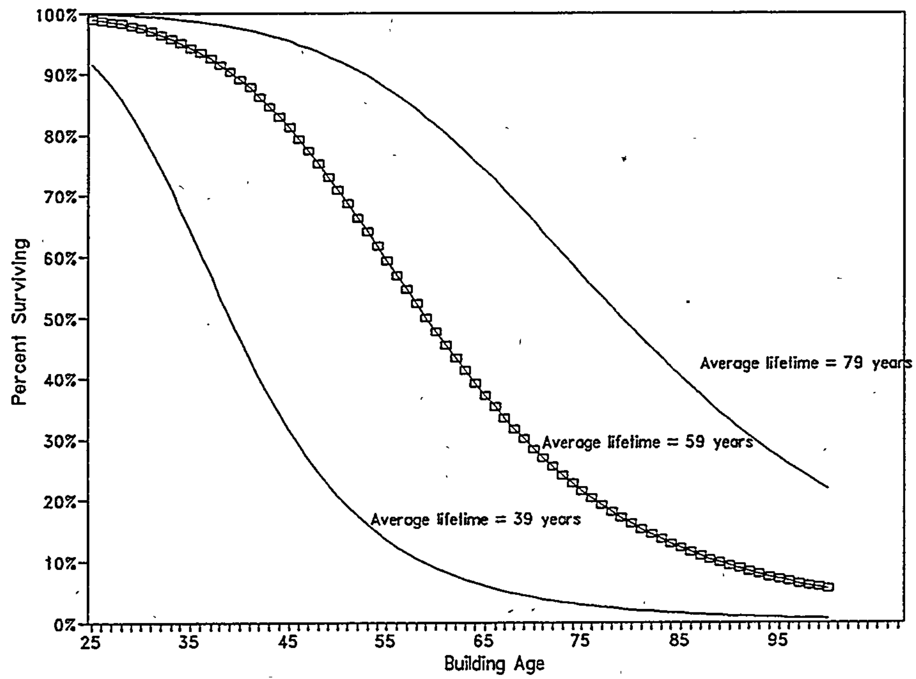


Figure 2. Floorspace Survival Function Sensitivity to Average Building Lifetimes

Floorspace Submodule

The Floorspace Submodule utilizes the Census Division building specific floorspace forecasts from the NEMS Macroeconomic Activity Module (MAM) as its primary driver. The Floorspace Submodule applies a convolution to backcast the floorspace stock to its original construction years, and then simulates building retirements using a logistic decay function. Surviving floorspace from the previous year is subtracted from the demanded floorspace forecast from MAM to yield new floorspace additions. In the event that the new additions computations produces 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. This range is applied in alternative approaches described in Chapter 2 of this report, for those models in which building lifetime is an input. The building retirement function used in the Floorspace Submodule depends upon the values of two user inputs: average building lifetime (avgage) and gamma. The current values for these model inputs are 59 years and 5.4 respectively. The survival rate used in the retirement function is the reciprocal of the term, (1 + (building age/average building lifetime)$^{\gamma}$).

Existing floorspace retires over a longer time period if the average building lifetime is increased or over a shorter time as the average lifetime is reduced as depicted in Figure 2. The gamma user input partly determines the shape of the survival rate function that defines the acceleration of the rate of retirement around the average building lifetime. The effect of different values of gamma is another consideration. As the value of gamma increases, the function declines precipitously as it nears the average lifetime value. This implies that the vast majority of buildings will retire at or very near the average lifetime. Large values of gamma should be avoided since 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 half of the floorspace will survive 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.

As demonstrated previously, gamma 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 new equipment is introduced, resulting in an erratic consumption time path.

Average building lifetimes are positively related to consumption; the longer the average building lifetime, the more slowly that new (higher efficiency) construction enters the market, and the lower the average efficiencies remain for the existing 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.

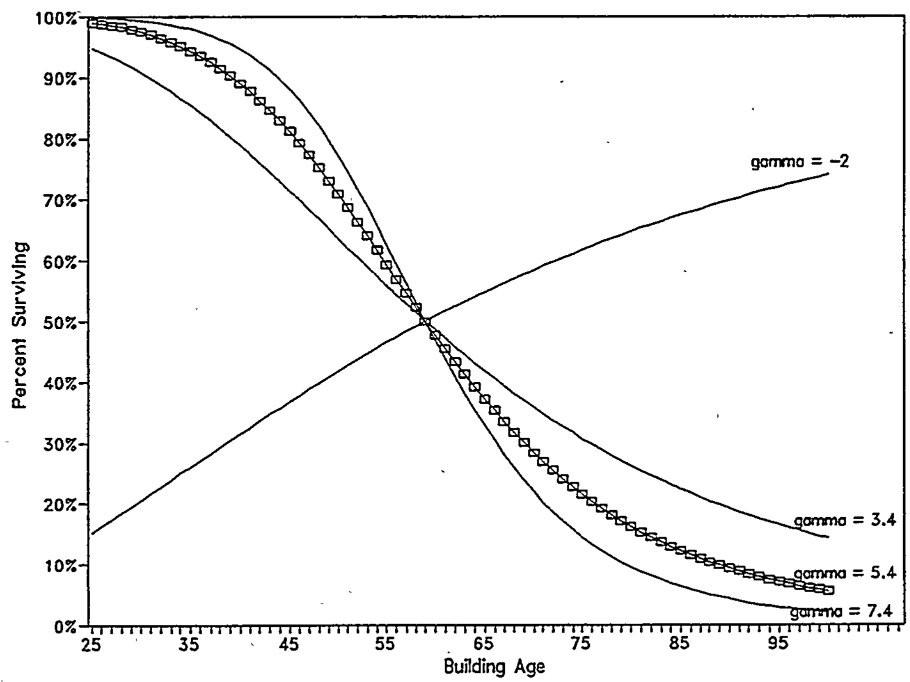


Figure 3. Alternative Gamma Assumptions and Results

The NEMS Commercial Sector Demand Module is designed to accept user inputs for gamma and average building lifetime, by Census Division and building type. This flexibility enables the Module to reflect the distinguishing characteristics of the different building types.

The equations that characterize the Floorspace Submodule are provided in the next section, Floorspace Equations.

Equation (4-1) backcasts CBECS 1989 floorspace stock to original construction years, for years prior to 1990. Equation (4-2) calculates surviving floorspace as the product of new floorspace and the floorspace survival rate. Equation (4-3) calculates new additions to floorspace based on the floorspace forecast generated by the NEMS MAM and the building retirement rates. This calculation is performed for the fourteen building types forecasted in the MAM: Amusement, Automotive, Dormitory, Education, Health, Hotel, Manufacturing Warehouse, Miscellaneous, Office, Public Service, Religious, Store, and Warehouse. Equation (4-4) calculates new floorspace additions for the NEMS Commercial Module by mapping the MAM floorspace categories to the NEMS Commercial Module floorspace categories.

Floorspace Equations

$$CMNewFloorSpace_{r,b,y} = \frac{CMExFlr89_{r,b,v}}{SurvFraction_{r,\,b,\,y-v,\,avgage_b,\,\gamma_b}} \quad (4\text{-}1)$$

where v ranges over each of the five floorspace vintage ranges and represents the average year of construction (1921, 1952, 1965, 1975, and 1985). In this case, y ranges from 1921 through 1989.

$$SurvFloorTotal_{r,b,y} = \sum_{v} (CMNewFloorSpace_{r,b,v} \times SurvFraction_{r,b,y-v,avgage_b,\gamma_b}) \quad (4\text{-}2)$$
$$\forall r, b, y$$

$$DRINewFloorspace_{r,\hat{b},y} = (MC\_COMMFLSP_{r,\hat{b},y} - (MC\_COMMFLSP_{r,\hat{b},y-1} * (1.0 - DRIBldgRetireRate_r))) * 10^3, \ \forall r,\hat{b},y \quad (4\text{-}3)$$

$$CMNewFloorspace_{r,b,CURIYR} = \sum_{\hat{b}} (DRItoCBECS_{b,\hat{b}} \times DRINewFloorspace_{r,\hat{b}}) \quad (4\text{-}4)$$
$$\forall r, b, y$$

Service Demand Submodule

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 energy use intensities (EUIs), efficiencies of equipment, efficiencies of building shells, and short-term price elasticities. In addition, service demand is decremented by demand satisfied by district services, solar space heating, solar water heating, and daylighting.

Energy use intensities represent the average amount of energy required to obtain a given service for a defined area. Currently the model uses Energy Use Intensity (EUI) estimates developed from conditional demand analysis of the CBECS 1989 consumption survey disaggregated by service, building type, and Census Division. 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. EUI values therefore must be greater than one since no service can be delivered without some energy. It is not recommended that EUIs be considered as a scenario varying model inputs since the values used in the NEMS Commercial Module are developed directly from an extensive energy consumption survey.

Service demand is estimated differently for major and minor services. Space heating and space cooling, which are major services, are sensitive to the building shell efficiencies. The service demand intensities are a function of inverse weighted equipment efficiencies and EUIs for the major services. The inverse weighted efficiencies, developed in a spreadsheet outside of the mainframe NEMS environment, using the equipment regional average efficiencies and regional market shares of fuel use by service, correspond to the equipment stock existing in CBECS 1989 floorspace.

Service demands for existing and new floorspace are computed by multiplying the EUIs adjusted for equipment efficiencies (and building shell efficiencies for space heating and space cooling), and existing and new floorspace respectively. Building shell efficiencies for existing and 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. The present shell efficiencies are indexed to the average 1989 values by building type and Census Division.

The portion of service demand satisfied by district services, solar space heating, solar water heating, and daylighting is computed using market shares for district services and exogenous forecasts for renewable energy for the commercial sector. The penetration of district services and solar energy changes the amount of service demand, affecting the end-use consumption for the major services. The incorporation of solar and district 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 short term price elasticity of demand is currently provided for space heating and space cooling, and the parameters currently included in the Commercial Module are set to -0.10 for these services. This value is representative of estimates provided in the literature as first referenced in Table A-2. The elasticities represent the short-term price responsiveness of space heating and space cooling service demands in the model. The values for the elasticities must necessarily be nonpositive since the services are *normal goods*, meaning that, as fuel prices increase, the quantity demanded of energy services declines. At present, service demand is assumed to retire at an annual rate of 5%. This simplifying assumption is currently used in place of equipment vintaging methods. The equations that calculate service demand are provided in the next section, Service Demand Equations, Equations (4-5) through (4-20).

Equations (4-5) and (4-6) initially calculate service demand in existing and new buildings respectively, as functions of service demand intensity, shell efficiency, and floorspace, for the major services. Equations (4-7) and (4-8) initially calculate service demand for minor services, excluding office equipment, in existing and new buildings respectively. Office equipment service demand is initially calculated for existing and new buildings in Equations (4-9) and (4-10) respectively.

Equations (4-11) and (4-12) modify the service demand calculation in existing and new buildings respectively to account for the contribution of district services for the end-uses of space heating, space cooling, and water heating. Equations (4-13) and (4-14) modify the service demand calculations to account for the contribution of solar renewable energy sources toward meeting commercial sector service demands in existing and new buildings respectively.

Price elasticities of service demand are treated in Equations (4-15) through (4-18), in which the fuel-share weighted price elasticities are computed (Equations (4-15) and (4-16)) and applied to existing (Equation (4-16)), new (Equation (4-17)) and retiring (Equation (4-18)) service demands. The amount of service demand that must be met (net of retiring service demand) is calculated in Equation (4-20).

Service Demand Equations

$$\begin{aligned} ServDmdExBldg_{s,b,r,y} &= ServDmdInten1989_{s,b,r} \times 10^{-3} \\ &\times ShellEffIndex_{b,r,1} \times SurvFloorTotal_{r,b,y} \\ &\forall\ r,\ s \in \{MajServ\}\ ,\ b\ ;\ y \end{aligned} \tag{4-5}$$

where the third subscript on ShellEffIndex is 1 for the shell efficiency of the original stock and 2 for the shell efficiency of new construction.

$$\begin{aligned} NewServDmd_{s,b,r,y} &= ServDmdInten1989_{s,b,r} \times 10^{-3} \\ &\times ShellEffIndex_{b,r,2} \times CMNewFloorspace_{r,b,y} \\ &\forall\ r\ ,\ s \in \{MajServ\}\ ,\ b\ ;\ y \end{aligned} \tag{4-6}$$

$$\begin{aligned} ServDmdExBldg_{s,b,r,y} &= ServDmdInten1989_{s,b,r} \times 10^{-3} \times SurvFloorTotal_{r,b,y} \\ &\forall\ r\ ,\ b\ ,\ s \in \{MinServ\}\ ,\ y \end{aligned} \tag{4-7}$$

$$\begin{aligned} NewServDmd_{s,b,r,y} &= ServDmdInten1989_{s,b,r} \times 10^{-3} \times CMNewFloorspace_{r,b,y} \\ &\forall r\ ,\ s \in \{MinServ\}\ ,\ b\ ,\ y \end{aligned} \tag{4-8}$$

$$\begin{aligned} ServDmdExBldg_{s,b,r,y} &= ServDmdExBldg_{s,b,r,y} \times OfficeEquipMktPen_{b,y} \\ &\forall\ r\ ,\ b\ ;\ for\ s = OfcEquip\ ,\ y \end{aligned} \tag{4-9}$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \times OfficeEquipMktPen_{b,y} \quad \textbf{(4-10)}$$
$$\forall\ r\ ,b\ ;\ for\ s = OfcEquip\ ,\ y$$

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \times (1.0 - DistrictHeatShare_{r,b,s}) \quad \textbf{(4-11)}$$
$$for\ all\ r\ ,b\ ;\ for\ all\ s = 1,...CMNumDistServ\ ,\ y$$

$$NewServDmd_{s,r,b,y} = NewServDmd_{s,b,r,y} \times (1.0 - DistrictHeatShare_{r,b,s}) \quad \textbf{(4-12)}$$
$$for\ all\ r\ ,\ b\ ;\ for\ all\ s = 1,...CMNumDistServ\ ,\ y$$

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - \left(\frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} \times \frac{CMNewFloorspace_{r,b,y}}{TotalFloorspace_{r,b,y}}\right) \quad \textbf{(4-13)}$$
$$for\ all\ r\ ,b\ ;\ for\ s = 1,...CMNumSolarServ,y$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} - \left(\frac{SolarRenewableContrib_{r,s,y}}{CMNumBldg} \times \frac{CMNewFloorspace_{r,b,y}}{TotalFloorspace_{r,b,y}}\right) \quad \textbf{(4-14)}$$
$$for\ all\ r\ ,b\ ;\ for\ s = 1,...CMNumSolarServ,y$$

$$ServiceDemandElasticity_{r,s,f} = ShortRunPriceElasofDmd_{r,s,f} \times \left(\frac{Price_{f,r,y} - Price_{f,r,1989}}{Price_{f,r,1989}}\right) \quad \textbf{(4-15)}$$
$$for\ all\ f = 1,...CMNumMajFl\ ,\ y\ ,\ r\ ,\ s$$

$$SDCompositeElas_{r,b,s,y} = \sum_{f=1}^{CmNumMajFl} (ServiceDemandElasticity_{r,s,f,y} \times PrevYrFuelShrServ_{r,b,s,f})$$
$$\forall r,b;\ s = 1,...CMNumSDElas\ ,\ y$$

(4-16)

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \times (1.0 - SDCompositeElas_{r,b,s}) \quad \textbf{(4-17)}$$
$$\forall r,b;\ s = 1,...CMNumSDElas;\ y\ from\ 1991\ to\ 2010$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \times (1.0 - SDCompositeElas_{r,b,s}) \quad \textbf{(4-18)}$$
$$\forall\ r\ ,b\ ;\ for\ s = 1,...CmNumSDElas\ ;\ for\ y\ from\ 1991\ to\ 2010$$

$$RetireServDmd_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \times (1.0 - SurvivingProportion) \quad \textbf{(4-19)}$$
$$\forall\ s,b,r;\ y\ from\ 1991\ to\ 2010$$

$$ServDmdSurv_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} - RetireServDmd_{s,b,r,y} \quad \textbf{(4-20)}$$
$$for\ all\ s,b,r;\ y\ from\ 1991\ to\ 2010$$

Technology Choice Submodule

The Technology Choice Submodule models the economic decision-making process by which commercial agents choose equipment to meet their end-use demands. The Commercial Module segments energy consumers into three categories based on the equipment choice process.

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 into three behavior rules and eleven 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 prejudices regarding certain equipment types or fuels. In addition, the intertemporal decision-making process modeled by the distribution of time preference premiums allows for a variety of commercial agents' attitudes about the desirability of current versus future expenditures with regards 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.

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 to be constant across choices, and these other attributes do not influence the technology choice decision modeled by the algorithm.

Table 9. Array of Technology Choices and Consumer Behaviors

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

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. The technologies can be represented as a cost surface that is linear with respect to the tradeoffs between O&M and fuel costs and increasing with respect to capital costs. This means 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 addition to this tradeoff, this component involves some 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 requires a method to weight 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. As previously described, 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 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 graphically in Table 9 and described in further detail below.

Behavior Rules

The NEMS Commercial Sector Demand Module simulates this range of economic factors 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 smallest annualized cost without regard to currently installed fuels or technologies,

- **Same Fuel Rule** -- Purchase equipment that uses the same fuel as existing and retiring equipment, but given that choice minimize costs, and

- **Same Technology Rule** -- Purchase (or keep) the same class of technology as the existing and retiring equipment, choosing from equipment models within the technology class.

The 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 1989. This source compares buildings with respect to the physical characteristics. Data regarding the ownership and occupants of commercial building forms the basis of proportions of the market that act according to each behavior rule for each decision type. The CBECS 1989 data is combined with consumer behavior literature to develop the behavior rule proportions incorporated in the Commercial Sector Demand Module. Changing these proportions impacts final consumption estimates. Three scenarios are presented in Volume II of this report that illustrate the outcomes when the market is not segmented by behavior rules and all agents behave according to a single rule.

Supporting data from CBECS 1989 includes building stock ownership patterns for 1989. This data is presented in Table 10. The categories provided are:

Total Floorspace of All Buildings

Total Floorspace of All Nongovernment Owned Buildings

Owner Occupied

Nonowner Occupied

Table 10. Floorspace Ownership and Occupancy

BEHAVIOR RULE PARAMETER ESTIMATION

Floorspace Ownership and Occupancy Patterns

	Total Flrspc.	Government Owned		Nongovt Owned	Nongovernment Owner Occupied		Nongovernment Non-owner Occupied	
Assembly	6,838	1,395	20.4%	5,443	5,118	74.8%	325	4.8%
Education	8,148	6,313	77.5%	1,835	1,822	22.4%	13	0.2%
Food Sales	792	5	0.6%	787	610	77.0%	177	22.3%
Food Service	1,167	109	9.3%	1,058	932	79.9%	126	10.8%
Health Care	2,054	495	24.1%	1,559	1,456	70.9%	103	5.0%
Lodging	3,476	622	17.9%	2,854	2,517	72.4%	337	9.7%
Mercantile/Service	12,365	399	3.2%	11,966	7,985	64.6%	3,981	32.2%
Office	11,802	2,353	19.9%	9,449	6,644	56.3%	2,805	23.8%
Warehouse	9,253	597	6.5%	8,656	5,871	63.4%	2,785	30.1%
Other	6,673	1,479	22.2%	5,194	2,964	44.4%	2,230	33.4%
TOTAL:	62,568	13,767	22.0%	48,801	35,919	57.4%	12,882	20.6%

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

- 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 Owner Occupied.

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.

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 building 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

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, and

- **Retrofit** -- Choose retrofit equipment to replace existing equipment in existing buildings or leave existing equipment in place.

For new buildings, consumers using the least cost behavior rule choose from among all current technologies and all fuels. 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).

For replacement equipment, consumers using the least cost behavior rule choose from among all current technologies. Consumers using the same fuel behavior rule choose from among current technologies which use the same fuel as in retiring buildings. Consumers using the same technology behavior rule choose the least costly vintage of the same technology as in retiring buildings.

For the existing/retrofit decision, consumers using the least cost behavior rule choose from current and previous vintage (existing) technologies. For this decision, existing equipment capital costs are sunk costs, meaning that these costs are set to zero. Consumers using the same fuel behavior rule for the existing/retrofit decision choose between current and previous vintage (existing) technologies use the same fuel as in surviving buildings. Consumers using the same technology behavior rule for the existing/retrofit decision, in effect, choose to keep (i.e., take no action) rather than replace the existing technology in surviving buildings.

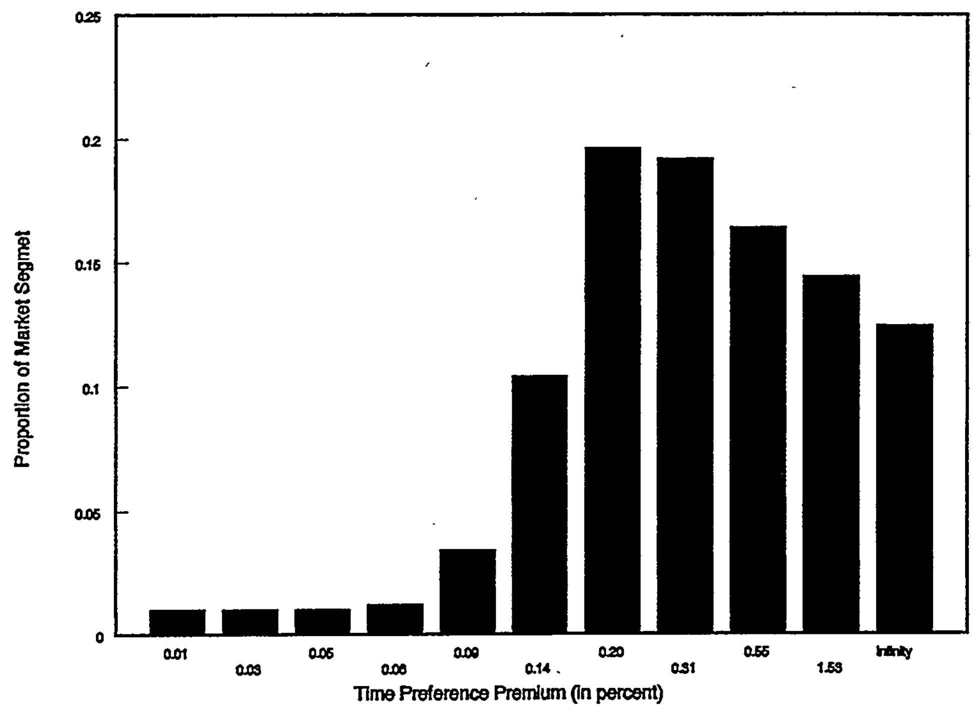


Figure 4. Distribution of Time Preference Premiums

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 distribution of the consumer's interest rate premium impacts results in several aspects. If the distribution is more dense 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. Figure 4 illustrates the shape of the distribution of time preference premiums currently employed in the NEMS Commercial Sector Demand Module. These values have been developed using case studies on the payback period or time preferences regarding the adoption of a specific technology. The module currently uses expected physical equipment lifetime as the discount horizon.

Technology Menu

Equipment availability, installed capital costs, operating and maintenance costs, energy efficiencies and lifetimes are specified exogenously. Equipment availability pertains to the set of technologies currently in the marketplace; not all available technologies are economically feasible, and therefore are not 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 fixed unit costs. 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

Table 11. 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

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 1989 initial historical market shares are based on an analysis of CBECS 1989 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 1995 due to federally mandated minimum equipment efficiency standards.

The effects of varying time preference premiums, interest rates and capacity factors are best described by working through the basic computations of the Technology Choice Submodule. Technology choices are made by comparing annualized unit costs for technologies which are available in the marketplace.

Annualized costs are used to generate a consistent basis for comparison for equipment alternatives with different lifetimes. Annualized costs are composed of three components: annualized installed capital costs, annual operating and maintenance costs (O&M), and annual fuel costs.

Commercial sector consumers' time preference is a distribution, as described previously. 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 and expected physical equipment lifetime.

Annualized installed capital costs apply to new equipment purchased for new floorspace, replacement equipment in existing floorspace, and retrofit equipment in existing floorspace. Capital costs are zero for existing equipment (in the retrofit decision), because these are sunk costs. 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 annual fuel cost per unit of service demand is a function of equipment efficiency and fuel prices.

Consolidate Choices From Segments

Once the technology choices have been selected for each service demand segment, these choices need to be consolidated for each combination of fuel, service, Census Division, building type and decision type. The proportions of each service met by each fuel from the consumer time preference and behavior rule segments are consolidated by weighting with the service demand proportions.

The consolidated efficiencies of the equipment used to meet each service demand, by fuel, are calculated by weighting the efficiencies from each time preference and behavior rule service demand segment. A reciprocal averaging procedure is needed for efficiency because the weights (service demands) are measured in units of energy out, while the efficiencies being averaged are in units of (energy out/energy in).

The equations that comprise the Technology Choice Submodule are presented in the next section, Equations (4-21) through (4-50). Equation (4-21) calculates the basic element required for the technology competition for new and replacement decisions: the annualized technology cost. The annualized technology cost is a function of the technology-specific installed unit capital cost, capacity factor, discounting premium, operating and maintenance cost, expected technology lifetime, and equipment performance characteristics.

Equations (4-22) through (4-24) illustrate the comparisons performed within the technology competition for new and replacement equipment to determine the least-cost alternative under the three behavior rules recognized by the Technology Choice Submodule. These three equations produce logical variables that rank the available technology selections based on the behavior rules.

Equations (4-25) through (4-29) are market share calculations for the new and replacement equipment decisions. Equations (4-25) through (4-27) aggregate technology shares across time preference premium segments within each behavior rule for the Least Cost, Same Fuel, and Same Technology behavior rules respectively. Equations (4-28) and (4-29) are aggregations across the behavior rules.

Equations (4-30) through (4-36) perform analogous calculations to the previous Technology Choice Submodule calculations, for equipment retrofit decisions. In the case of a retrofit decision, the consumer has the option of retaining existing equipment (incurring zero additional capital cost, resulting in a different annualized capital cost calculation) as calculated in Equation (4-30), or selecting replacement equipment. The comparisons and aggregations required to determine the optimal choice for retrofit decisions are calculated in Equations (4-31) through (4-36).

Equations (4-37) through (4-50) calculate the Submodule outputs required by the End-Use Consumption Submodule, the NEMS Report Writer, the internal Commercial Module Report Writer, and the Load and Demand Side Management Module (LDSM) of the NEMS Electricity Market Module (EMM). These components are developed by aggregating the choices from the decision processes previously described, accounting for the technology characterizations that correspond to the choices.

Technology Choice Equations

$$
\begin{aligned}
AnnualCostTech_{p,t,v} = & \left[\frac{TechCost_{t,v,1}}{CapacityFactor_{r,b,s}} \times \left(\frac{MCREALRMGBLUS_{y}}{100} + TimePrefPrem_{p}\right)\right. \\
& \div \left[1.0 - \left(1.0 + \frac{MCREALRMGBLUS_{y}}{100} + TimePrefPrem_{p}\right)^{-TechLife_{t,v}}\right] \\
& + TechCost_{t,v,2} \\
& + \sum_{\acute{y}=y}^{y+TechLife_{t,v}-1} \left[ConvFactor \times \frac{P_{f,r,\acute{y}}}{TechLife_{t,v}}\right] \times \left[\frac{1.0}{TechEff_{r,s,t,v}}\right] \\
& ConvFactor = 8.76 \text{ for } s \neq lighting.\ ;\ 0.03343 \text{ for } s = lighting
\end{aligned}
$$

(4-21)

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 subscript v in this case represents the model of equipment (characterized by equipment efficiency, year of availability, and capital costs, which vary across equipment models) of a specific technology class t.

Least Cost Decision Rule -- search across all t' and v':

$$\begin{aligned} &\textit{Find } t, v \textit{ such that } AnnualCostTech_{p,v,t} \le AnnualCostTech_{p,t',v'} \\ &\forall\, t', v' \\ &\textit{then } LCTNRAF_{p,1} = t \,,\ LCTNRAF_{p,2} = v \end{aligned} \tag{4-22}$$

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

Same Fuel Decision Rule -- search across all t' and v' using the same fuel as the existing stock

$$\begin{aligned} &\textit{Find } t, v \ni AnnualCostTech_{p,v,t} \le AnnualCostTech_{p,t',v'} \\ &\forall t', v' \ni FuelByTech(t',f) = 1 \,,\ FuelByTech(t,f) = 1 \,, \\ &\forall\, p \,, \forall\, f \in \{MajFuel\} \\ &\textit{then } LCTNRSF_{p,f,1} = t \,,\ LCTNRSF_{p,f,2} = v. \\ &\textit{If } \nexists\, t \ni FuelByTech(t,f) = 1 \,, \\ &\textit{then } LCTNRSF_{p,f,1} = LCTNRSF_{p,f,2} = 0 \end{aligned} \tag{4-23}$$

where FuelByTech(t',f) = 1 if technology t' uses fuel f, and is 0 otherwise.
$LCTNRSF_{p,f,1}$ represents the technology class with the least annualized cost, and
$LCTNRSF_{p,f,2}$ represents the technology model with the least annualized cost.

Same Technology Decision Rule -- search across all models v' within technology class t:

$$\begin{aligned} &\textit{Find } v \textit{ such that } AnnualCostTech_{p,t,v} \le AnnualCostTech_{p,t,v'} \\ &\forall\, p,t,v', \textit{ then } LCVNRST_{p,t} = v \end{aligned} \tag{4-24}$$

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

$$\begin{aligned} LCMSNR_{t,v} &= \sum_{p} TimePrefProp_{p}, \\ &\forall\, p \ni LCTNRAF_{p,1} = t \,, \textit{ and } LCTNRAF_{p,2} = v \,, \\ &\forall\, t \,, v \end{aligned} \tag{4-25}$$

$$SFMSNR_{t,v} = \sum_{p} [TimePrefProp_p \times PrevYrFuelShrServ_{r,b,s,f}]$$
$$\forall\, p \ni LCTNRSF_{p,f,1} = t \text{ , and } LCTNRSF_{p,f,2} = v \text{ ,} \quad \text{(4-26)}$$
$$\forall\, t,v \text{ ; } \forall\, f \in \{MajFuel\}$$

$$STMSNR_{t,v} = [\sum_{p} TimePrefProp_p] \times [\sum_{\acute{v}} PrevYrTechShrServ_{r,b,s,t,\acute{v}}] \quad \text{(4-27)}$$
$$\forall\, p \text{ such that } LCVNRST_{p,t} = v \text{ ; } \forall\, \acute{v} \text{ ; } \forall\, v \text{ ; } \forall\, t$$

$$\begin{aligned} MS_{b,s,1,t,v} = {} & BehaviorShare_{b,1,1} \times LCMSNR_{t,v} \\ & + BehaviorShare_{b,1,2} \times SFMSNR_{t,v} \\ & + BehaviorShare_{b,1,3} \times STMSNR_{t,v} \\ & \forall\, t, v \end{aligned} \quad \text{(4-28)}$$

The third subscript of the market share variable, MS, as well as the second subscript of BehaviorShare represents the decision type. The value 1 represents new equipment, 2 represents replacement equipment, and 3 represents retrofit equipment.

$$\begin{aligned} MS_{b,s,2,t,v} = {} & BehaviorShare_{b,2,1} \times LCMSNR_{t,v} \\ & + BehaviorShare_{b,2,2} \times SFMSNR_{t,v} \\ & + BehaviorShare_{b,2,3} \times STMSNR_{t,v} \\ & \forall t, v \end{aligned} \quad \text{(4-29)}$$

$$\begin{aligned} ACE_{t,v} = {} & TechCost_{t,v,2} \\ & + [\sum_{\acute{y}=y}^{y+0.5 \times TechLife_{t,v}-1} ConvFactor \times \left(\frac{P_{f,r,\acute{y}}}{0.5 * TechLife_{t,v}} \right)] \\ & \times \frac{1.0}{TechEff_{r,s,t,v}} \\ & \forall\, t, v \text{ . } ConvFactor = 8.76 \text{ for } s \neq lighting \text{ ; } 0.03343 \text{ for } s = lighting \end{aligned} \quad \text{(4-30)}$$

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

$$\begin{aligned}&\textit{Find } \acute{t}\ ,\ \acute{v} \textit{ such that } AnnualCostTech_{p,\acute{t},\acute{v}} \leq ACE_{t,v}\\&\textit{if none found },\ \acute{t} = t\ ,\ \acute{v} = v.\\&\textit{If } t\ ,v \textit{ unavailable },\textit{then } \acute{t} = \acute{v} = 0\\&LCTRetAF_{p,t,v,1} = \acute{t}\ ,\ LCTRetAF_{p,t,v,2} = \acute{v}\\&\forall\ p,t,v\end{aligned} \tag{4-31}$$

$$\begin{aligned}&\textit{Find } \acute{t}\ ,\ \acute{v}\ \ni\ AnnualCostTech_{p,\acute{t},\acute{v}} \le ACE_{t,v}\ ,\ f_{\acute{t}} = f_{t}\\&\textit{If } \exists\ \acute{t}\ ,\ \acute{v} \rightarrow \acute{t} = t\ ,\ \acute{v} = v.\\&\textit{If } \nexists\ t\ ,v\ , \rightarrow \acute{t} = \acute{v} = 0\ ,\\&\textit{then } LCTRetSF_{p,t,v,1} = \acute{t}\ ,\ LCTRetSF_{p,t,v,2} = \acute{v}\end{aligned} \qquad (4\text{-}32)$$

$$\begin{aligned}LCMSRet_{t,v} = \sum_{p,\acute{t},\acute{v}} &[TimePrefProp_p \times PrevYrTechShrServ_{r,b,s,\acute{t},\acute{v}}]\\&\forall p\ ,\ \acute{t}\ ,\ \acute{v}\ \ni\\&LCTRetAF_{p,\acute{t},\acute{v},} = t\ ,\ LCTRetAF_{p,\acute{t},\acute{v},2} = v,\\&\forall\ t\ ,\ v\end{aligned} \qquad (4\text{-}33)$$

$$\begin{aligned}SFMSRet_{t,v} = \sum_{p,\acute{t},\acute{v}} &[TimePrefProp_p \times PrevYrTechShrServ_{r,b,s,\acute{t},\acute{v}}]\\&\forall p\ ,\ \acute{t}\ ,\ \acute{v}\ \ni\\&LCTRetSF_{p,\acute{t},\acute{v},1} = t\ ,\ LCTRetSF_{p,\acute{t},\acute{v},2} = v,\\&\forall t\ ,\ v\end{aligned} \qquad (4\text{-}34)$$

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

$$STMSRet_{t,v} = PrevYrTechShrServ_{r,b,s,t,v} \quad \forall\ t\ ,\ v \qquad (4\text{-}35)$$

$$MS_{b,s,3,t,v} = BehaviorShare_{b,3,1} \times LCMSRet_{t,v} + BehaviorShare_{b,3,2} \times SFMSRet_{t,v} + BehaviorShare_{b,3,3} \times STMSRet_{t,v} \quad \forall\, t\,,\, v \tag{4-36}$$

$$FS_{r,b,s,d,f} = \sum_t \sum_v [MS_{b,s,d,t,v} \times FuelbyTech_{t,f}] \quad \forall\, d\,;\, f \in \{MajFuel\}, \text{ where } FuelbyTech_{t,f} = 1 \text{ if } t \text{ uses } f\,, \; 0 \text{ elsewhere} \tag{4-37}$$

The fourth subscript of the fuel share variable, FS, represents the decision type. The value 1 represents new equipment, 2 represents replacement equipment, and 3 represents retrofit equipment.

$$AE_{r,b,s,d,f} = \frac{FS_{r,b,s,d,f}}{\sum_{t,v} \dfrac{MS_{b,s,d,t,v} \times FuelbyTech_{t,f}}{TechEff_{r,s,t,v}}]} \quad \forall\, d = 1,2,3\,;\, f \in \{MajFuel\} \text{ if } \exists\, t\,,\, v \ni MS_{b,s,d,t,v} \times FuelbyTech_{t,f} \neq 0\,, \text{ otherwise } 0 \tag{4-38}$$

The value d=1 represents new equipment decisions, d=2 represents replacement equipment decisions, and d=3 represents retrofit equipment decisions.

$$FuelShrofService_{r,b,s,f} = \frac{NSD_{r,b,s,y} \times FS_{r,b,s,1,f}}{TSD_{r,b,s,y}} + \frac{RSD_{r,b,s,y} \times FS_{r,b,s,2,f}}{TSD_{r,b,s,y}} + \frac{SSD_{r,s,b,y} \times FS_{r,b,s,3,f}}{TSD_{r,b,s,y}} \text{ where } TSD_{r,b,s,y} > 0\,,\; 0 \text{ elsewhere} \quad \forall\, f \in \{MajFuel\}\,,\, y \tag{4-39}$$

$$TechShrServ_{r,b,s,f} = \frac{NSD_{r,b,s,y} \times MS_{r,b,s,1,t,v}}{TSD_{r,b,s,y}} + \frac{RSD_{r,b,s,y} \times MS_{r,b,s,2,t,v}}{TSD_{r,b,s,y}} + \frac{SSD_{r,s,b,y} \times MS_{r,b,s,3,t,v}}{TSD_{r,b,s,y}} \quad \textbf{(4-40)}$$

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

$$\forall\, t \text{ , } v$$

$$AverageEfficiency_{r,b,s,f} = \frac{FuelShrofService_{r,b,s,f}}{\sum_{t,v} [\frac{TechShrServ_{r,b,s,t,v} \times FuelbyTech_{t,f}}{TechEff_{r,s,t,v}}]} \quad \textbf{(4-41)}$$

$$\textit{if } \exists\, t \ni TechShrServ_{r,b,s,t,v} \times FuelbyTech_{t,f} \neq 0 \text{ , }$$

$$0 \textit{ otherwise}$$

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

$$DecAvgEff_{r,s,1,f,y} = \frac{\sum_{b} [FS_{r,b,s,1,f} \times NSD_{r,b,s,y}]}{\sum_{b} [\frac{FS_{r,b,s,1,f} \times NSD_{r,b,s,y}}{AE_{r,b,s,1,f}}]} \quad \textbf{(4-42)}$$

$$\forall f \in \{MajFuels\} \text{ , } y$$

The third subscript of DecAvgEff represents the equipment decision type, with 1=new equipment, 2=replacement equipment, and 3=retrofit equipment.

$$DecAvgEff_{r,s,2,f,y} = \frac{\sum_{b} [FS_{r,b,s,2,f} \times RSD_{r,b,s,y}]}{\sum_{b} [\frac{FS_{r,b,s,2,f} \times RSD_{r,b,s,y}}{AE_{r,b,s,2,f}}]} \quad \textbf{(4-43)}$$

$$\forall f \in \{MajFuels\} \text{ , } y = CURIYR$$

$$DecAvgEff_{r,s,3,f,y} = \frac{\sum_b [FS_{r,b,s,3,f} \times SSD_{r,b,s,y}]}{\sum_b [\frac{FS_{r,b,s,3,f} \times SSD_{r,b,s,y}}{AE_{r,b,s,3,f}}]} \quad \text{(4-44)}$$
$$\forall f \in \{MajFuels\}, y$$

The third subscript of DecFuelShare represents decision type. The value 1 represents new equipment, the value 2 represents replacement equipment, and the value 3 represents retrofit equipment.

$$DecFuelShare_{r,s,1,f,y} = \frac{\sum_b [FS_{r,b,s,1,f} \times NSD_{r,b,s,y}]}{\sum_b NSD_{r,b,s,y}} \quad \text{(4-45)}$$
$$\forall y, f \in \{MajFuels\}$$

$$DecFuelShare_{r,s,2,f,y} = \frac{\sum_b [FS_{r,b,s,2,f} \times RSD_{r,b,s,y}]}{\sum_b RSD_{r,b,s,y}} \quad \text{(4-46)}$$
$$\forall y, f \in \{MajFuels\}$$

$$DecFuelShare_{r,s,3,f,y} = \frac{\sum_b [FS_{r,b,s,3,f} \times SSD_{r,b,s,y}]}{\sum_b SSD_{r,b,s,y}} \quad \text{(4-47)}$$
$$\forall y, f \in \{MajFuels\}$$

$$CMUSAvgEff_{s,f,y} = \frac{\sum_r \sum_b [FuelShrofService_{r,b,s,f} \times TSD_{r,b,s,y}]}{\sum_r \sum_b \sum_{t,v} [\frac{TechShrServ_{r,b,s,t,v} \times FuelbyTech_{t,f} \times TSD_{r,b,s,y}}{TechEff_{r,s,t,v}}]} \quad (4\text{-}48)$$

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

$$AverageEfficiency_{r,b,s,f} = PrevYrAverageEfficiency_{r,b,s,f} \times (1.0 + EffGrowthRate_s) \quad (4\text{-}49)$$

$$\forall s \in \{MinServ\}, \forall r, b, for\ f = electricity$$

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

$$DecFuelShare_{r,s,d,f,y} = FuelShrofService_{r,b,s,1} \quad (4\text{-}50)$$

$$\forall s \in \{MinServ\}, \forall r, b, d, y$$

End-Use Consumption Submodule

End-use consumption is defined as energy consumed by equipment, and is expressible in physical units, such as gallons of fuel oil, cubic feet of natural gas, or kilowatt-hours of electricity. To compare services that use several different energy sources, energy consumption is expressed in Btu based units.

The End-use Consumption Submodule converts the average equipment efficiency and fuel proportions calculated in the Technology Choice Submodule into energy consumption estimates. The effects of non-utility electricity generation, non-building energy consumption in the commercial sector, and minor fuels consumption are addressed in the End-use Consumption Submodule. In addition, airborne emissions are calculated on the basis of end-use consumption of fuels.

The End-use Consumption Submodule calculates combustion emissions of seven pollutants:

- sulfur oxides (SO_x),
- nitrogen oxides (NO_x),
- carbon monoxide (CO),
- carbon dioxide (CO_2),
- methane (CH_4),
- non-methane volatile organic compounds (VOC); and
- total carbon.

The emissions estimates are based on consumption levels calculated in the End-Use Consumption Submodule. The emission factors are calculated from EPA sources and are not recommended to be modified as a user input for scenario analysis.

Commercial sector non-utility generation is the cogeneration of electricity in commercial buildings, independent of the electric utility. A building with non-utility generating systems consumes fossil fuels or renewable energy to meet some or all of its electricity demand, and may produce surplus power to sell back to a utility. A forecast of electricity cogeneration is developed through the following procedure.

First, a baseline cogeneration forecast by Census Division, building type, and generating fuel is developed by multiplying the previous year's figures by a growth factor that is currently a constant value based on historical growth rates of commercial sector nonbuilding energy consumption. The baseline forecast is then modified to reflect the effects of cross-price elasticity between the generating fuel price and the price of electricity. Current year prices are normalized relative to the AEO93 price forecasts used to generate the growth factors. The cross-price elasticity effect is not considered for the renewable fuels of wood and Municipal Solid Waste (MSW).

The End-Use Consumption Submodule accounts for commercial sector consumption of five minor fuels. These fuels do not account for sufficient 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 and are modeled by constant growth rates over the forecast horizon based on analysis of the historical State Energy Data System (SEDS) minor fuel share growth rates.

The equations that characterize the End-Use Consumption Submodule are provided in the next section, comprising Equations (4-51) through (4-63). Equations (4-51) and (4-52) initially calculate End-Use Consumption for the major fuels, first for all major services except lighting (4-51), then for lighting (4-52) to account for the lumen-based units for lighting technologies.

Equation (4-53) sums the end-use consumption previously calculated across services, and Equation (4-54) sets the calculated value to the unbenchmarked total. Equation (4-55) sums unbenchmarked end-use consumption across Census Divisions to obtain national unbenchmarked end-use consumption.

Equations (4-56) and (4-57) calculate minor fuel consumption based on historical data and minor fuel share growth rates from the State Energy Data System (SEDS) data base. Equations (4-58) through (4-60) calculate the contribution of cogenerated electricity in the commercial sector. Equations (4-61) through (4-63) incorporate the cogeneration of electricity, and sum across buildings to obtain unbenchmarked and final end-use consumption measures required as inputs to the Benchmarking Submodule.

End-Use Consumption Equations

$$EndUseConsump_{f,s,b,r} = \frac{FuelShrofService_{r,b,s,f} \times TSD_{r,b,s,y}}{AverageEfficiency_{r,b,s,y}} \quad \forall r\ ,\ b\ ,\ s \neq lighting\ ,\ f \in \{MajFuels\} \qquad (4\text{-}51)$$

$$EndUseConsump_{f,s,b,r} = \frac{FuelShrofService_{r,b,s,f} \times TSD_{r,b,s,y}}{AverageEfficiency_{r,b,s,y}} \div 0.03343 \quad \forall r\ ,\ b\ ;\ for\ s = lighting \qquad (4\text{-}52)$$

$$FinalEndUseCon_{f,b,r,y} = \sum_{s} EndUseConsump_{f,s,b,r} \quad \forall f \in \{MajFuels\}\ ,\ \forall\ b\ ,\ r\ ,\ y \qquad (4\text{-}53)$$

$$OnBenchCon_{f,r,b,y} = FinalEndUseCon_{f,b,r,y} \quad \forall f \in \{MajFuels\}, \forall b, r, y \qquad (4\text{-}54)$$

$$CMUSConsump_{s,f,y} = [\sum_{r}\sum_{b} EndUseConsump_{f,s,b,r}] \times 10^{-3} \quad \forall s \in \{MajServ\}, f \in \{MajFuels\} \qquad (4\text{-}55)$$

$$FinalEndUseCon_{f,b,r,y} = \frac{CMSEDS_{f,r}}{CMNumBldg}, \; if \; y = 1990 \quad \forall f \in \{MinFuels\}, \forall r, b \qquad (4\text{-}56)$$

$$FinalEndUseCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y-1} \times [1.0 + CMMinFuelGrowth_{f,r}] \quad \forall f \in \{MinFuels\}, \forall r, b; \; for \; y \; from \; 1992 \; to \; 2010 \qquad (4\text{-}57)$$

$$CMBaselineElCogen_{r,b,f,y} = CMBaselineElCogen_{r,b,f,y-1} \times CMCogenGrowthFactor_{y} \quad \forall r, b, f; \; y \; from \; 1992 \; to \; 2010 \qquad (4\text{-}58)$$

$$CMCogenEl_{r,b,f} = CMBaselineElCogen_{r,b,f} \times \left(\frac{\left(\frac{Price_{f,r,y}}{CMBaselinePrice_{r,f,y}}\right)}{\left(\frac{Price_{elec,r,y}}{CMBaselinePrice_{r,elec,y}}\right)} \right)^{CMCogenCrossPriceElast_f} \quad \forall f \notin \{RenewFuels\}\ ;\ y > 1991\ ,$$
$$= CMBaselineElCogen_{r,b,f}\ ,\ otherwise \quad \forall\ r\ ,\ b\ ,f\ ,\ y \tag{4-59}$$

$$CMCogenConsump_{r,b,f} = (CMCogenEl_{r,b,f} \times CMCogenTEtoELrat_f) \times CMDeltaRecipEff_f \quad \forall\ r,\ b\ ,\ f \tag{4-60}$$

$$FinalEndUseCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y} + CMCogenConsump_{r,b,f} \quad \forall\ r\ ,\ b\ ;\ for\ f \notin \{MinFuels\} \tag{4-61}$$

$$CMFinalUnbenchCon_{f,r,y} = \sum_b UnBenchCon_{f,b,r,y} \quad \forall f \in \{MajFuels\}\ ,\ \forall\ r\ ,\ y \tag{4-62}$$

$$CMFinalEndUse_{f,r,y} = \sum_b FinalEndUseCon_{f,b,r,y} \quad \forall f\ ,\ r\ ,\ y \tag{4-63}$$

Benchmarking

The NEMS Commercial Sector Demand Module is benchmarked to historical SEDS 1990 consumption data. A multiplicative factor is used to tie the 1990 Commercial Module results to the SEDS historical value for 1990. This benchmarking procedure is used since the coverage of the commercial sector reported in SEDS is greater than that reported in CBECS 1989 on which the Commercial Module is based.

SEDS data is applicable for estimating annual end-use consumption by sector and by state. One objective of SEDS is to maintain a time series that is consistently defined over time and across sectors. Because SEDS collects and organizes data gathered for numerous reporting and regulatory reasons, there are many sources of uncertainty in the data that are difficult to quantify when compounded. In addition, the survey forms that collect these data are generally targeting energy suppliers who report sales or distribution at state levels.

CBECS is a triennial survey that gathers information on building characteristics and energy consumption and expenditures from end-users. Building information is collected through personal interviews with managers, owners and tenants of commercial buildings. Subsequently, billing data with consumption and expenditure information is obtained from the energy suppliers. CBECS contains much detailed information on building activity, installed equipment, age, energy consumption, fuels, etc.

Comparison of CBECS and SEDS

The main differences between CBECS and SEDS.

1. Uncertainty. SEDS gathers data from many heterogenous sources with differing errors. CBECS quantifies uncertainty by computing a relative standard error.

2. Extent of Coverage. CBECS data are from a representative sample. Some SEDS information is from samples, other data are from EIA forms which are mandatory for all firms active in the industry.

3. Frequency. SEDS is mainly concerned with maintaining a time series data base that is consistently measured through time and across industrial sectors. CBECS is a triennial survey that does not provide data or estimates of the intervening years.

4. Respondents. SEDS respondents are generally suppliers and/or distributors of energy who report sales and income. CBECS respondents are end-users who report consumption and expenditures.

5. Disaggregation. SEDS is disaggregated into major sectors and states. No further disaggregation of SEDS is possible. CBECS is disaggregated into Census Division, fuel, building vintage, building size, building use, etc.

The equations that calculate the final, benchmarked commercial sector energy consumption series that are output to the NEMS Report Writer are provided in the next section, Benchmarking Equations. Equation (4-64) calculates the discrepancy between historical energy consumption values from the SEDS data base and the calculated results for building consumption, by Census Division and fuel, for all fuels excluding renewable fuels. Equation (4-65) calculates final end-use consumption, incorporating the growth in nonbuilding consumption for the current forecast year. Equation (4-66) calculates airborne emissions attributable to the commercial sector.

Benchmarking Equations

$$CMNonBldgCon_{f,r} = CMSEDS_{f,r} - CMFinalEndUse_{f,r,y=FIRSYR} \quad \forall\ r\ ,\ f \notin \{RenewFuels\} \qquad \textbf{(4-64)}$$

$$\begin{aligned} CMFinalEndUse_{f,r,y} &= CMFinalEndUse_{f,r,y} \\ &+ CMNonBldgCon_{f,r} \\ &\times [1.0 + (y - FIRSYR) \times CMNonBldgGrowth_{f,r}] \\ &\forall\ r, f \notin \{RenewFuels\}\ ,\ y \end{aligned} \qquad \textbf{(4-65)}$$

$$CMEmissions_{f,e,r} = \frac{CMFinalEndUse_{f,r,y} \times EmissionFactor_{f,e}}{2204.62\ \frac{lbs}{MT}} \qquad \forall f\ ,\ e\ ,\ r\ ,\ y \qquad \textbf{(4-66)}$$

Appendix A. Input Data and Variable Descriptions

Introduction

This Appendix describes the input data, parameter estimates, variables, and data calibrations that currently reside on the EIA mainframe 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.

The variable list provided in Table A-1 references the input data, parameter estimates, variables, and module outputs described in the Appendix. Each item in Table A-1 is accompanied by its definition, modeling dimensions, equation reference from Chapter 4 of the Main Text of this report, subroutine reference, classification, and units. This Appendix contains the data sources, analytical methodologies, and parameter estimates corresponding to the table. Table A-2 categorizes the items contained in Table A-1 and references the Appendix A page that describes the item where applicable.

The remainder of Appendix A contains supporting discussion including data selection and calibration procedures, required transformations, levels of disaggregation, and model input files. Model output files are provided in Volume II of this report.

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-1	Floorspace	CMNewFloorSpace	New commercial floorspace by Census Division, building type, and year	Calculated variable	million sq ft
		CMExFlr89	Existing commercial floorspace for 1989 by Census Division, building type, and floorspace vintage range	Module input	million sq ft
		SurvFraction	Fraction of commercial floorspace surviving by Census Division, building type, building age, average age of building type, floorspace survival function curvature parameter	Calculated variable	unitless
4-2	Floorspace	SurvFloorTotal	Total surviving commercial floorspace by Census Division, building type, and year	Calculated variable	million sq ft
4-3	Floorspace	DRINewFloorspace	New commercial floorspace by Census Division and building type, and building types are those from NEMS Macroeconomic Activity Module (MAM) floorspace forecast	Received as input from MAM	million sq ft
		MC_COMMFLSP	Existing commercial floorspace by Census Division and building type, and building types are those from NEMS Macroeconomic Activity Module (MAM) floorspace forecast	Received as input from MAM	billion sq ft
		DRIBldgRetireRate	Building retirement rate assumed in MAM floorspace forecast by Census Region (4 Regions)	Received as input from MAM	unitless
4-4	Floorspace	DRItoCBECS	Conversion factors that map the building types in MAM to the CBECS building types used in the NEMS Commercial Module	Module input	unitless
4-5	Service Demand	ServDmdExBldg	Service demand in existing commercial floorspace, by Census Division, building type, major service, and year	Calculated variable	trillion Btu out (not lighting), billion lumen years out (lighting)
		ServDmdInten1989	Service demand intensity based on 1989 energy consumption, by Census Division, building, and service	Calculated variable	thousand Btu out/sq ft (not lighti lumen years out/sq ft (lighting)
		ShellEffIndex	Building shell efficiency index by Census Division and building	Module input	unitless

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-6	Service Demand	NewServDmd	Service demand in new commercial floorspace, by Census Division, building type, major service and year	Calculated variable	trillion Btu out (not lighting), billion lumen years out (lighting)
		ShellEffIndex	Building shell efficiency index by Census Division and building type, for new floorspace	Module Input	unitless
4-7	Service Demand	ServDmdExBldg	Service Demand in existing commercial floorspace, by Census Division, building type, minor service, and year	Calculated variable	thousand Btu out/sq ft (not lighti lumen years out/sq ft (lighting)
4-8	Service Demand	NewServDmd	Service demand in new commercial floorspace, by Census Division, building type, minor service and year	Calculated variable	thousand Btu out/sq ft (not lighti lumen years out/sq ft (lighting)
4-9	Service Demand	ServDmdExBldg	Service demand in existing commercial floorspace, by Census Division, building type, office equipment, and year	Calculated variable	thousand Btu out/sq ft (not lighti lumen years out/sq ft (lighting)
		OfficeEquipMktPen	Office equipment market penetration rate by building type in existing buildings, and year	Module Input	unitless
4-10	Service Demand	NewServDmd	Service demand in new commercial floorspace, by Census Division, building type, office equipment, and year	Calculated variable	thousand Btu out/sq ft (not lighti lumen years out/sq ft (lighting)
		OfficeEquipMktPen	Office equipment market penetration rate by building type in new buildings, and year	Module Input	unitless
4-11	Service Demand	DistrictHeat Share	Proportion by which to decrement the corresponding service demand calculated previously. It represents the proportion of service demand satisfied by district services, by Census Division, building type, and service, for the services served by district systems, in new buildings	Module Input	unitless
		CMNumDistServ	Number of services served by district services. Currently=3:	Module Input	unitless

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-12	Service Demand	DistrictHeatShare	Proportion by which to decrement the corresponding service demand calculated previously. It represents the proportion of service demand satisfied by district services, by Census Division, building type, and service, for the services served by district systems, in new buildings	Module Input	unitless
4-13	Service Demand	SolarRenewableContrib	For each service s (up to CMnumSolarServ), year y, and Census Division r, the aboslute amount by which to decrement the corresponding service demand calculated previously. It represents the amount of service demand satisfied by solar energy, in existing buildings	Module Input	thousand Btu out/sq ft (not light) lumen years out/sq ft (lighting)
4-14	Service Demand	SolarRenewableContrib	For each service s (up to CMnumSolarServ), year y, and Census Division r, the aboslute amount by which to decrement the corresponding service demand calculated previously. It represents the amount of service demand satisfied by solar energy, in new buildings	Module Input	thousand Btu out/sq ft (not light) lumen years out/sq ft (lighting)
4-15	Service Demand	ShortRunPriceElasofDmd	Short-run price elasticities of demand for the major fuels, by fuel and service. This is the ratio of percent change in previously calculated service demand for service s to percent change in price of fuel f from last year to the current year	Module parameter	unitless
		Price	Fuel price received from NEMS system, by Census Division, fuel and year	Received from NEMS System	constant dollars per million Btu
4-16	Service Demand	SDCompositeElas	Composite price elasticity of service demand calculated from fuel-specific price elasticities for year y and fuel proportions of service demand from year y-1 by Census Division, building, service, and fuel	Calculated variable	unitless
		PrevYrFuelShrServ	Previous year's fuel proportion of service demand by Census Division, building, service and fuel	Calculated variable	unitless

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-19	Service Demand	RetireServDmd	Service demand in retiring floorspace by Census Division, building type, service and year	Calculated variable	thousand Btu out/sq ft (not lighting) lumen years out/sq ft (lighting)
4-21	Technology Choice	AnnualCostTech	Annualized unit cost of a technology by technology class, technology vintage, and consumer time preference premium, incorporating annualized cost of capital per unit service demanded, annualized operating and maintenance cost per unit of service demanded, annualized fuel costs per unit service demand, and consumer time preference premiums	Calculated variable	(constant dollars/(thousand Btu/ [yr)]) for non-lighting; (constant dollars/lumen)/year for lighting
		TechCost	Annualized cost of capital per unit service demanded	Module Input	same units as AnnualCostTech
		CapacityFactor	Equipment capacity factor by Census Division, building type and service	Module Input	unitless
		MC_REALRMGBLUS	10-year Treasury bond rate from NEMS MAM forecast by year	Received from NEMS MAM	unitless
		TimePrefPrem	Consumer time preference premium segment	Module Input	unitless
		TechLife	Expected economic lifetime by technology class and technology vintage	Module Input	years; unitless where used as an [exponent]
		TechCost	Annualized operating and maintenance cost per unit service demanded	Module Input	same units as AnnualCostTech
		ConvFactor	Conversion factor to map lighting units from lumen based to Btu based units	Module Input	unitless
4-22	Technology Choice	LCTNRAF	A logical variable that flags the least cost technology for new and replacement decisions across all fuels, within a consumer time preference premium segment	Logical variable	unitless

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-23	Technology Choice	FuelbyTech	A logical variable indicating whether a technology uses the fuel upon which the query is performed	Logical variable	unitless
		LCTNRSF	A logical variable that flags the least cost technology for new and replacement decisions within a same fuel behavior rule, within a consumer time preference premium segment	Logical variable	unitless
4-24	Technology Choice	LCVNRST	A logical variable that flags the least cost technology vintage for new and replacement decisions within a same technology behavior rule, within a consumer time preference premium segment	Logical variable	unitless
4-25	Technology Choice	LCMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the least cost behavior rule for new and replacement decisions	Calculated variable	unitless
		TimePrefProp	Proportions of consumers in each time preference premium segment	Module Input	unitless
4-26	Technology Choice	SFMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for new and replacement decisions	Calculated variable	unitless
4-27	Technology Choice	STMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for new and replacement decisions	Calculated variable	unitless
4-28	Technology Choice	BehaviorShare	Share of commercial consumers following each of the three behavior rules, for new and replacement decision types	Module Input	unitless

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-30	Technology Choice	ACE	Annualized equipment cost by technology class and technology vintage, for retrofit decision type	Calculated variable	same units as AnnualCostTech
4-31	Technology Choice	LCTRetAF	A logical variable that flags the least cost technology for retrofit decisions across all fuels for the least cost behavior rule, within a consumer time preference premium segment	Logical variable	unitless
4-32	Technology Choice	LCTRetSF	A logical variable that flags the least cost technology for retrofit decisions across all fuels for the same fuel behavior rule, within a consumer time preference premium segment	Logical variable	unitless
4-33	Technology Choice	LCMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the least cost behavior rule for retrofit decisions	Calculated variable	unitless
4-34	Technology Choice	SFMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for retrofit decisions	Calculated variable	unitless
4-35	Technology Choice	STMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for retrofit decisions	Calculated variable	unitless
4-36	Technology Choice	MS	Equipment market share aggregation for retrofit decision type, across behavior rules	Calculated variable	unitless
4-37	Technology Choice	FS	Fuel share by Census Division, service, building, fuel and decision type	Calculated variable	unitless
4-38	Technology Choice	AE	Average equipment efficiency by Census Division, building type, service, fuel, and decision type	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lighting

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-39	Technology Choice	FuelShrofService	Fuel share of service demand by Census Division, building type, service, and fuel	Calculated variable	unitless
		NSD, TSD, RSD, SSD	Abbreviations for New Service Demand, Total Service Demand, Retiring Service Demand, and Surviving Service Demand as defined previously	Calculated variables	thousand Btu out/sq ft (not lighting) lumen years out/sq ft (lighting)
4-40	Technology Choice	TechShrServ	Technology share of service by Census Division, building type, service, and fuel	Calculated variable	unitless
4-41	Technology Choice	AverageEfficiency	Average equipment efficiency by Census Division, building type, service and fuel	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lightg.
4-42	Technology Choice	DecAvgEff	Average equipment efficiency by Census Division, service, fuel and year, for new equipment decisions	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lightg.
4-43	Technology Choice	DecAvgEff	Average equipment efficiency by Census Division, service, fuel and year, for replacement equipment decisions	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lightg
4-44	Technology Choice	DecAvgEff	Average equipment efficiency by Census Division, service, fuel and year, for retrofit equipment decisions	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lightg.
4-45	Technology Choice	DecFuelShare	Fuel share by Census Division, service, building, fuel and year, for new equipment decisions	Calculated variable	unitless
4-46	Technology Choice	DecFuelShare	Fuel share by Census Division, service, building, fuel and year, for replacement equipment decisions	Calculated variable	unitless
4-47	Technology Choice	DecFuelShare	Fuel share by Census Division, service, building, fuel and year, for retrofit equipment decisions	Calculated variable	unitless
4-48	Technology Choice	CMUSAvgEff	Average equipment efficiency aggregated across all Census Divisions to obtain U.S. averatge, by service, fuel, and year	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lightg.

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-49	Technology Choice	AverageEfficiency	Average equipment efficiency by Census Division, building, and service for the minor services	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lighting.
		PrevYrAverageEfficiency	Previous year average equipment efficiency by Census Division, building type, and service for the minor services	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lighting.
		EffGrowthRate	Efficiency growth rate by service for the minor services	Module Input	unitless
4-51	End-Use Consumption	EndUseConsump	End-use consumption for major fuels, by Census Division, building type, service and fuel, excluding lighting	Calculated variable	trillion Btu
4-52	End-Use Consumption	EndUseConsump	End-use consumption for lighting, by Census Division and building type (this equation incorporates lighting conversion factor required to convert lumen units to Btu units)	Calculated variable	trillion Btu
4-53	End-Use Consumption	FinalEndUseCon	Final end-use consumption by Census Division, building, fuel and year, summed across services, for major fuels	Calculated variable	trillion Btu
4-54	End-Use Consumption	UnBenchCon	Unbenchmarked end-use consumption for major fuels, by Census Divisoin, building type, fuel, and year	Calculated variable	trillion Btu
4-55	End-Use Consumption	CMUSConsump	End-Use consumption by service, fuel and year, summed across Census Division and building type	Calculated variable	quadrillion Btu
4-56	End-Use Consumption	FinalEndUseCon	Final end-use consumption by Census Division, building type, fuel and year	Calculated variable	trillion Btu
		CMSEDS	State Energy Data System (SEDS) historical consumption by Census Division and fuel for the commercial sector	Module Input	trillion Btu
4-57	End-Use Consumption	FinalEndUseCon	Final end-use consumption for minor fuels, by Census Division, building, fuel, and year	Calculated variable	trillion Btu
		CMMinFuelGrowth	Minor fuel growth rates by Census Division and fuel, for the minor	Module Input	unitless

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-58	End-Use Consumption	CMBaselineElCogen	Baseline commercial sector electricity cogeneration forecast by Census Division, building type, fuel, and year	Calculated variable	trillion Btu
		CMCogenGrowthFactor	Growth factor for cogeneration of electricity by year	Module input	unitless
4-59	End-Use Consumption	CMCogenEl	Forecasted commercial sector cogeneration by Census Division, building type, and generating fuel	Calculated variable	trillion Btu
		Price	Generating fuel price by Census Division, fuel, and year	Received from NEMS Supply Modules	constant dollars per million Btu
		CMBaselinePrice	AEO 1993 reference price by Census Division, fuel, and year	Module input	constant dollars per million Btu
		RenewFuels	Renewable energy source fuels	Module input	unitless
4-60	End-Use Consumption	CMCogenConsump	Consumption of generating fuels for cogeneration by Census Division, building type, and generating fuel	Calculated variable	trillion Btu
		CMCogenTEtoELrat	Thermal energy to electricity generation ratio by generating fuel	Module input	unitless
		CMDeltaRecipEffic	Change in the reciprocal of the efficiency of the generating fuel, by generating fuel	Module input	unitless
4-61	End-Use Consumption	FinalEndUseCon	Final end-use consumption including cogeneration by Census Division, building type, fuel, and year	Calculated variable	trillion Btu
4-62	End-Use Consumption	CMFinalUnbenchCon	Final unbenchmarked consumption across all building types, by Census Division, fuel, and year, for major fuels	Calculated variable	trillion Btu
4-63	End-Use Consumption	CMFinalEndUse	Final end-use consumption including cogeneration by Census Division, fuel, and year	Calculated variable	trillion Btu

Table A-1. NEMS Commercial Module Inputs and Outputs

Equation Number in Chapter 4 of Volume I Main Txt.	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units
4-64	Benchmarking	CMNonBldgCon	Nonbuilding consumption by Census Division and fuel	Calculated variable	trillion Btu
4-65	Benchmarking	CMFinalEndUse	Final end-use consumption by Census Division, fuel and year for all fuels excluding renewable fuels	Module output	trillion Btu
		CMNonBldgGrowth	Nonbuilding growth rate factors by Census Division and fuel	Module Input	unitless
4-66	Benchmarking	CMEmissions	Emissions of airborne pollutants by the commercial sector, by Census Division, fuel, and emissions compound	Module output	metric tons
		EmissionFactor	Emissions factor by fuel and emissions compound	Module Input	lbs/million Btu

Table A-2. Classification and Page References for Table A-1

CALCULATED VARIABLES

Item	Definition and Dimensions	Page Reference
CMNewFloorSpace	New commercial floorspace by Census Division, building type, and year	
SurvFraction	Fraction of commercial floorspace surviving by Census Division, building type, building age, average age of building type, floorspace survival function curvature parameter	A-56
SurvFloorTotal	Total surviving commercial floorspace by Census Division, building type, and year	
ServDmdExBldg	Service demand in existing commercial floorspace, by Census Division, building type, major service, and year	
ServDmdInten1989	Service demand intensity based on 1989 energy consumption, by Census Division, building, and service	
NewServDmd	Service demand in new commercial floorspace, by Census Division, building type, major service and year	
ServDmdExBldg	Service Demand in existing commercial floorspace, by Census Division, building type, minor service, and year	
ServDmdExBldg	Service demand in existing commercial floorspace, by Census Division, building type, office equipment, and year	
NewServDmd	Service demand in new commercial floorspace, by Census Division, building type, office equipment, and year	
SDCompositeElas	Composite price elasticity of service demand calculated from fuel-specific price elasticities for year y and fuel proportions of service demand from year y-1 by Census Division, building, service, and fuel	A-57
PrevYrFuelShrServ	Previous year's fuel proportion of service demand by Census Division, building, service and fuel	A-45

Table A-2. Classification and Page References for Table A-1

CALCULATED VARIABLES

Item	Definition and Dimensions	Page Reference
RetireServDmd	Service demand in retiring floorspace by Census Division, building type, service and year	
AnnualCostTech	Annualized unit cost of a technology by technology class, technology vintage, and consumer time preference premium, incorporating annualized cost of capital per unit service demanded, annualized operating and maintenance cost per unit of service demanded, annualized fuel costs per unit service demand, and consumer time preference premiums	
LCMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the least cost behavior rule for new and replacement decisions	
SFMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for new and replacement decisions	
STMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for new and replacement decisions	
ACE	Annualized equipment cost by technology class and technology vintage, for retrofit decision type	
LCMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the least cost behavior rule for retrofit decisions	

Table A-2. Classification and Page References for Table A-1

CALCULATED VARIABLES

Item	Definition and Dimensions	Page Reference
SFMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for retrofit decisions	
STMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for retrofit decisions	
MS	Equipment market share aggregation for retrofit decision type, across behavior rules	
FS	Fuel share by Census Division, service, building, fuel and decision type	
AE	Average equipment efficiency by Census Division, building type, service, fuel, and decision type	A-35
FuelShrofService	Fuel share of service demand by Census Division, building type, service, and fuel	
NSD, TSD, RSD, SSD	Abbreviations for New Service Demand, Total Service Demand, Retiring Service Demand, and Surviving Service Demand as defined previously	
TechShrServ	Technology share of service by Census Division, building type, service, and fuel	
AverageEfficiency	Average equipment efficiency by Census Division, building type, service and fuel	A-35
DecAvgEff	Average equipment efficiency by Census Division, service, fuel and year, for new equipment decisions	

Table A-2. Classification and Page References for Table A-1

CALCULATED VARIABLES

Item	Definition and Dimensions	Page Reference
DecAvgEff	Average equipment efficiency by Census Division, service, fuel and year, for replacement equipment decisions	
DecAvgEff	Average equipment efficiency by Census Division, service, fuel and year, for retrofit equipment decisions	
DecFuelShare	Fuel share by Census Division, service, building, fuel and year, for new equipment decisions	
DecFuelShare	Fuel share by Census Division, service, building, fuel and year, for replacement equipment decisions	
DecFuelShare	Fuel share by Census Division, service, building, fuel and year, for retrofit equipment decisions	
CMUSAvgEff	Average equipment efficiency aggregated across all Census Divisions to obtain U.S. averatge, by service, fuel, and year	
AverageEfficiency	Average equipment efficiency by Census Division, building, and service for the minor services	A-35
PrevYrAverageEfficiency	Previous year average equipment efficiency by Census Division, building type, and service for the minor services	A-35
EffGrowthRate	Efficiency growth rate by service for the minor services	A-35
EndUseConsump	End-use consumption for major fuels, by Census Division, building type, service and fuel, excluding lighting	
EndUseConsump	End-use consumption for lighting, by Census Division and building type (this equation incorporates lighting conversion factor required to convert lumen units to Btu units)	

Table A-2. Classification and Page References for Table A-1

CALCULATED VARIABLES

Item	Definition and Dimensions	Page Reference
FinalEndUseCon	Final end-use consumption by Census Division, building, fuel and year, summed across services, for major fuels	
UnBenchCon	Unbenchmarked end-use consumption for major fuels, by Census Divisoin, building type, fuel, and year	
CMUSConsump	End-Use consumption by service, fuel and year, summed across Census Division and building type	
FinalEndUseCon	Final end-use consumption by Census Division, building type, fuel and year	
FinalEndUseCon	Final end-use consumption for minor fuels, by Census Division, building, fuel, and year	
CMBaselineElCogen	Baseline commercial sector electricity cogeneration forecast by Census Division, building type, fuel, and year	A-42
CMCogenEl	Forecasted commercial sector cogeneration by Census Division, building type, and generating fuel	A-42
CMCogenConsump	Consumption of generating fuels for cogeneration by Census Division, building type, and generating fuel	
FinalEndUseCon	Final end-use consumption including cogeneration by Census Division, building type, fuel, and year	
CMFinalUnbenchCon	Final unbenchmarked consumption across all building types, by Census Division, fuel, and year, for major fuels	
CMFinalEndUse	Final end-use consumption including cogeneration by Census Division, fuel, and year	
CMNonBldgCon	Nonbuilding consumption by Census Division and fuel	

Table A-2. Classification and Page References for Table A-1

LOGICAL VARIABLES

Item	Definition and Dimensions	Page Reference
LCTNRAF	A logical variable that flags the least cost technology for new and replacement decisions across all fuels, within a consumer time preference premium segment	I
FuelbyTech	A logical variable indicating whether a technology uses the fuel upon which the query is performed	
LCTNRSF	A logical variable that flags the least cost technology for new and replacement decisions within a same fuel behavior rule, within a consumer time preference premium segment	
LCVNRST	A logical variable that flags the least cost technology vintage for new and replacement decisions within a same technology behavior rule, within a consumer time preference premium segment	
LCTRetAF	A logical variable that flags the least cost technology for retrofit decisions across all fuels for the least cost behavior rule, within a consumer time preference premium segment	
MODULE INPUTS (INCLUDING INPUTS RECEIVED FROM OTHER NEMS MODULES)		
CMExFlr89	Existing commercial floorspace for 1989 by Census Division, building type, and floorspace vintage range	A-41
DRINewFloorspace	New commercial floorspace by Census Division and building type, and building types are those from NEMS Macroeconomic Activity Module (MAM) floorspace forecast	
DRIBldgRetireRate	Building retirement rate assumed in MAM floorspace forecast by Census Region (4 Regions)	
DRItoCBECS	Conversion factors that map the building types in MAM to the CBECS building types used in the NEMS Commercial Module	

Table A-2. Classification and Page References for Table A-1

MODULE INPUTS (INCLUDING INPUTS RECEIVED FROM OTHER NEMS MODULES)

Item	Definition and Dimensions	Page Reference
ShellEffIndex	Building shell efficiency index by Census Division and building type, for surviving floorspace.	A-55
ShellEffIndex	Building shell efficiency index by Census Division and building type, for new floorspace	A-55
OfficeEquipMktPen	Office equipment market penetration rate by building type in existing buildings, and year	A-43
OfficeEquipMktPen	Office equipment market penetration rate by building type in new buildings, and year	A-43
DistrictHeat Share	Proportion by which to decrement the corresponding service demand calculated previously. It represents the proportion of service demand satisfied by district services, by Census Division, building type, and service, for the services served by district systems, in new buildings	A-32
CMNumDistServ	Number of services served by district services. Currently=3:	
DistrictHeat Share	Proportion by which to decrement the corresponding service demand calculated previously. It represents the proportion of service demand satisfied by district services, by Census Division, building type, and service, for the services served by district systems, in new buildings	A-32
SolarRenewableContrib	For each service s (up to CMnumSolarServ), year y, and Census Division r, the aboslute amount by which to decrement the corresponding service demand calculated previously. It represents the amount of service demand satisfied by solar energy, in existing buildings	A-53

Table A-2. Classification and Page References for Table A-1

MODULE INPUTS (INCLUDING INPUTS RECEIVED FROM OTHER NEMS MODULES)

Item	Definition and Dimensions	Page Reference
SolarRenewableContrib	For each service s (up to CMnumSolarServ), year y, and Census Division r, the aboslute amount by which to decrement the corresponding service demand calculated previously. It represents the amount of service demand satisfied by solar energy, in new buildings	A-53
Price	Fuel price received from NEMS system, by Census Division, fuel and year	
TechCost	Annualized cost of capital per unit service demanded	A-26
CapacityFactor	Equipment capacity factor by Census Division, building type and service	A-24
MC_REALRMGBLUS	10-year Treasury bond rate from NEMS MAM forecast by year	
TimePrefPrem	Consumer time preference premium segment	A-49
TechLife	Expected economic lifetime by technology class and technology vintage	A-26
TechCost	Annualized operating and maintenance cost per unit service demanded	A-26
ConvFactor	Conversion factor to map lighting units from lumen based to Btu based units	
TimePrefProp	Proportions of consumers in each time preference premium segment	A-49
BehaviorShare	Share of commercial consumers following each of the three behavior rules, for new and replacement decision types	A-51
EffGrowthRate	Efficiency growth rate by service for the minor services	A-30

Table A-2. Classification and Page References for Table A-1

Item	Definition and Dimensions	Page Reference
MODULE INPUTS (INCLUDING INPUTS RECEIVED FROM OTHER NEMS MODULES)		
CMSEDS	State Energy Data System (SEDS) historical consumption by Census Division and fuel for the commercial sector	
CMMinFuelGrowth	Minor fuel growth rates by Census Division and fuel, for the minor	A-35
CMCogenGrowthFactor	Growth factor for cogeneration of electricity by year	A-42
Price	Generating fuel price by Census Division, fuel, and year	
CMBaselinePrice	AEO 1993 reference price by Census Division, fuel, and year	
RenewFuels	Renewable energy source fuels	
CMCogenTEtoELrat	Thermal energy to electricity generation ratio by generating fuel	
CMDeltaRecipEffic	Change in the reciprocal of the efficiency of the generating fuel, by generating fuel	
CMFinalEndUse	Final end-use consumption by Census Division, fuel and year for all fuels excluding renewable fuels	
CMNonBldgGrowth	Nonbuilding growth rate factors by Census Division and fuel	A-40
EmissionFactor	Emissions factor by fuel and emissions compound	A-38
MODULE-PARAMETERS		
ShortRunPriceElasofDmd	Short-run price elasticities of demand for the major fuels, by fuel and service. This is the ratio of percent change in previously calculated service demand for service s to percent change in price of fuel f from last year to the current year	A-57
MODULE OUTPUTS		
CMFinalEndUse	Final end-use consumption by Census Division, fuel and year for all fuels excluding renewable fuels	
CMEmissions	Emissions of airborne pollutants by the commercial sector, by Census Division, fuel, and emissions compound	A-38

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MODEL INPUT: Equipment Availability

MODEL COMPONENT: Technology Choice

DEFINITION: Availability of equipment technology *t* and model *v* in year *y*.

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., "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.

Arthur D. Little, Inc., "Discussion Charts; Task 1: Technology Status - Residential/ Commercial End-Use Equipment and Advanced Power Cycles," ADL reference 64460-09, prepared for U.S. Department of Energy, Energy Information Administration, March 1990, pp. 21, 42-49, 58-59.

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.

Mahoney, Daniel 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, pp. 4, 59, 139-140.

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, Energy Information Administration, Lighting in Commercial Buildings, EIA, Washington DC, March 1992, p. 41.

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 1990: Model Documentation, EIA, Washington DC, March 1990, pp. III-37 to III-39.

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

MODEL INPUT: Equipment Capacity Factor

MODEL COMPONENT: Technology Choice

DEFINITION: Capacity factor of equipment to meet service *s* in Census Division *r* in building type *b*. The capacity factor is the ratio of actual annual equipment output to output if equipment were run 100% of the time at full capacity.

DISCUSSION:

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. 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.

The averages for the cities in each Census Division are weighted by population and used to compute capacity factor by the following expression where 12 represents the number of months in a year, and is needed to balance the peak cooling requirement units ,

$$\text{Cooling Capacity Factor} = \frac{\text{Avg regional annual}}{\text{cooling reqrmt}} \times \frac{1000}{8760} \times \frac{12}{\text{peak cooling reqrmt}} \qquad \textbf{(A-1)}$$

$$\text{Heating Capacity Factor} = \frac{\text{Avg regional annual heating reqrmt}}{} \times \frac{1000}{8760} \times \frac{12}{\text{peak heating reqrmt}} \qquad \text{(A-2)}$$

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.

Department of Energy, Energy Information Administration, Lighting in Commercial Buildings, EIA, Washington DC, March 1992, p. 38.

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 of technology *k* of model *v*.

DISCUSSION:

Capital and installation costs are combined to form installed capital costs, based upon available data. In addition, the Technology Choice algorithm does not require the separation of capital and installation costs. Installed unit capital costs 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, and lighting technologies.

Installed Capital Cost. The forecasts for the installed capital cost for future technologies applied in the model are developed from Arthur D. Little, Inc.'s (ADL) research for all future equipment models except for 2010 equipment model which is not estimated by ADL. The values for 2010 equipment model technology are computed using Gas Research Institute (GRI) data. The expression used for the 2010 equipment model equipment and installation cost is,

$$\begin{array}{c}\textit{NEMS instld cptl cost}\\ \textit{for } 2010 \textit{ equip}\end{array} = \frac{\begin{array}{c}\textit{GRI instld cptl cost for}\\ 2010 \textit{ equip}\end{array}}{\begin{array}{c}\textit{GRI instld cptl cost for}\\ 1989 \textit{ equip}\end{array}} \times \begin{array}{c}\textit{ADL } 1989 \textit{ vintage}\\ \textit{instld cptl cost}\end{array} \qquad \textbf{(A-3)}$$

Space heating installed capital costs are taken from the EPRI report cited below, for current equipment models, and from GRI and/or ADL sources for estimates of future equipment models. For those technologies with available data from both ADL and GRI, an average cost for the 1989 equipment model is computed and future equipment models are based on the 1989 high efficiency vintage using a cost inflator from the GRI data. The computational method is expressed as,

$$\begin{array}{c}\textit{High efficiency 1989 vintage}\\ \textit{installed capital costs}\end{array} = \frac{\begin{array}{c}(\textit{GRI installed capital cost for 1989 vintage}\\ + \textit{ADL installed capital cost for 1989 vintage})\end{array}}{2} \qquad \textbf{(A-4)}$$

Due to the lack of sufficient available data, gas boiler equipment installed capital costs are computed as follows:

$$\begin{array}{c}\textit{Current average installed}\\ \textit{capital cost for Gas Boilers}\end{array} = \frac{\begin{array}{c}\textit{Current installed capital}\\ \textit{cost gas furnace}\end{array}}{\begin{array}{c}\textit{Installed capital cost}\\ \textit{high efficiency gas furnace}\end{array}} \times \begin{array}{c}\textit{Instld captl cost}\\ \textit{high efficiency gas boiler}\end{array} \qquad \textbf{(A-5)}$$

Installed capital costs for water heaters using electricity, natural gas, and distillate are directly obtained from the 1990 Annual Energy Outlook. The input data for space heating and water heating technologies utilizes a proportional factor based on professional expectations to account for such noneconomic factors as perceived safety and comfort concerns. The principal data sources for unit costs are the reports from EPRI, ADL, GRI, OTA, and EIA as cited below.

Operating & Maintenance Cost. Similarly, the O&M costs are also scaled in terms of GRI capital cost growth rates. The installed capital costs from GRI and ADL reports on future equipment model equipment were used along with the data on current O&M costs from EPRI to formulate a value for the O&M costs of future equipment models. The O&M cost for future equipment models is assumed to be 4% of the projected GRI installed capital costs. The O&M costs for future equipment models are computed by expression,

$$\frac{\text{NEMS installed capital costs}}{\text{for future models of equipment}} = \frac{\text{GRI first costs for future equipment} \times 4\%}{\text{GRI OM costs for new 1989 vintage equipment}} \times \frac{\text{EPRI average}}{\text{current OM costs}} \quad \text{(A-6)}$$

Equipment Efficiency. equipment efficiency is based on a simple average from all available sources reporting efficiencies. These sources include the EPRI, ADL, and GRI reports previously referred to as well as the 1990 AEO, the NES, and research by Geller.

Average Equipment Lifetime. The expected equipment lifetime is calculated as a simple average across the available data from the EPRI, ADL, GRI and DOE sources listed 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.,"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.

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.

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, 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.

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.

MODEL INPUT: Minor service equipment efficiency increment

MODEL COMPONENT: Technology Choice

DEFINITION: Annual efficiency improvement factor for the minor services of office equipment, refrigeration, and miscellaneous services.

DISCUSSION:

The estimated efficiency improvement factors for office equipment, refrigeration, and miscellaneous 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 2010 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 2010.

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.,"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: District service shares

MODEL COMPONENT: Service Demand

DEFINITION: Share of a service met by district services, including space heating, space cooling, and water heating, in Census Division *r*, building type *b*, and service *s*.

DISCUSSION:

District service shares calculated directly from the CBECS 1989 data base are currently included in the model. These shares are developed based upon district service consumption and floorspace by Census Division and building type, and are carried through the forecast period. The CBECS 1989 data base does not contain sufficiently stratified observations for district service consumption by building vintage. Accordingly, the district service shares are assumed constant across building vintages in the current analysis.

SOURCES:

Energy Information Administration, "Commercial Buildings Energy Consumption Survey 1989 data base," June 1992.

MODEL INPUT: Equipment efficiency

MODEL COMPONENT: Technology Choice

DEFINITION: Efficiency of technology *k* of model *v*, consuming fuel *f*.

DISCUSSION:

Equipment efficiencies for the services of space heating, space cooling, water heating, ventilation, cooking, and lighting 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 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., "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.

Arthur D. Little, Inc., "Discussion Charts; Task 1: Technology Status - Residential/ Commercial End-Use Equipment and Advanced Power Cycles," ADL reference 64460-09, prepared for U.S. Department of Energy, Energy Information Administration, March 1990, pp. 42-49, 58-59.

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

Mahoney, Daniel D., DRI Energy, "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, p. 4.

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.

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

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.

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

MODEL INPUT: Base year average equipment efficiency

MODEL COMPONENT: Service Demand

DEFINITION: Average efficiency of equipment existing in the base year for service *s*.

DISCUSSION:

Average equipment efficiency in the base year is estimated for space heating, space cooling, water heating, ventilation, cooking, and lighting by weighting efficiencies for specific technologies by the proportions of service demand met by each technology for all installed equipment. Proportions of 1989 (base year) commercial sector consumption served by the technologies from Commercial Buildings Characteristics 1989 and Lighting in Commercial Buildings are used as proxies for proportions of service demand. The individual technology efficiencies are composites of equipment efficiencies found in the EPRI, ADL, GRI, OTA, NES, AEO90, and Lighting in Commercial Buildings sources cited below.

Existing equipment efficiency is assumed to be an index with value 1.00 for office equipment and refrigeration systems in the base year. Office equipment and refrigeration systems introduced throughout the forecast period incorporate efficiency improvements as culled from a literature search. Efficiency improvements are reflected by values of the efficiency index that are greater than one that correspond to enhanced equipment.

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., "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.

Arthur D. Little, Inc., "Discussion Charts; Task 1: Technology Status - Residential/

Commercial End-Use Equipment and Advanced Power Cycles," ADL reference 64460-09, prepared for U.S. Department of Energy, Energy Information Administration, March 1990, pp. 42-49, 58-59.

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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.

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Department of Energy, Energy Information Administration, Commercial Buildings Characteristics 1989, EIA, Washington DC, June 1991, pp. 134-5, 146-7, 150.

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.

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

MODEL INPUT: Energy-use Intensity

MODEL COMPONENT: Service Demand

DEFINITION: Energy consumed per unit floorspace for service *s* in building type *b* in Census Division *r* in year *y*, Btu in/ft^2.

DISCUSSION:

EUI estimates developed by Pacific Northwest Laboratory using the CBECS 1989 data base are included in the module. These data are developed by Census Division, building type, and service.

SOURCES:

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.

MODEL INPUT: Airborne emissions from commercial sector activity

MODEL COMPONENT: End-Use Consumption

DEFINITION: Annual emissions factor by compound emitted, by fuel.

DISCUSSION:

Commercial sector emission factor estimates measured in lbs/MMBtu are included for the following airborne pollutants:

Forecasted Emissions
Total Carbon
Carbon Monoxide
Carbon Dioxide
Sulfur Oxides
Nitrogen Oxides
Volatile Organic Compounds (excluding Methane)
Methane
Particulate Matter

Emissions factors for EPA criteria pollutants (CO, CH_4, SO_x, NO_x, VOC's and particulates) are provided in the EPA source cited below. The emissions factor for total carbon is from research conducted by G. Marland and A. Pippin, also cited below. The emissions factor estimate for carbon dioxide from natural gas is derived by using the total carbon emission factor and the EPA estimates for those emissions which contain carbon, namely carbon monoxide and methane. Carbon dioxide is determined by the following transformation,

$$\begin{array}{c} CO_2\ Emiss \\ factor \end{array} = \begin{array}{c} Marland\ \&\ Pippin's \\ carbon\ coeff \\ of\ fuel \end{array} - \left(\frac{EPA\ emiss\ factor\ CO}{\frac{CO\ atomic weight}{atomic weight of\ carbon in\ CO}} + \frac{EPA\ emiss\ factor\ CH_4}{\frac{CH_4\ atomic weight}{atomic weight of\ carbon in\ CH_4}} \right) \times \frac{\begin{array}{c} atomic wt \\ of\ CO_2 \end{array}}{\begin{array}{c} atomic wt \\ of\ carbon in\ CO_2 \end{array}} \qquad \text{(A-7)}$$

SOURCES:

Compilation of Air Pollution Emission Factors, Vol. 1 Stationary Point and Area Sources, Supplement A, U.S. Environment Protection Agency, October 1986.

Decision Analysis Corporation of Virginia, *Airborne Emission Factors for the National Energy Modeling System (NEMS)*, prepared for the Energy Information Administration, Contract no. DE-AC01-92EI21946, November 20,1992.

Decision Analysis Corporation of Virginia, *Emissions Estimates for 1990*, prepared for the Energy Information Administration, contract no. DE-AC01-92EI21946, December 4,1992.

Marland, G. and A. Pippin, "United States Emissions of Carbon Dioxide to the Earth's Atmosphere by Economic Activity," *Energy Systems and Policy (1990)*, pp. 319-336.

MODEL INPUT: Minor fuel consumption, minor fuel growth rate

MODEL COMPONENT: End-Use Consumption

DEFINITION: Minor fuel final end-use consumption is measured in Btu in for $f \in$ {residual fuel oil, LPG, coal, motor gasoline, kerosene} for Census Division *r* for year *y*.

Minor fuel growth rate is the annual increment multiplied by previous year (*y-1*) minor fuel end-use consumption for Census Division *r* in year *y*.

DISCUSSION:

1990 minor fuel consumption is set to the published SEDS historical value by fuel and Census Division. Forecasted values of minor fuel consumption are developed by multiplying the previous year's minor fuel consumption by a growth factor that is based upon SEDS historical share growth for minor fuels.

The growth factor is calculated using the historical shares of minor fuels from 1985-1990 based on published SEDS data. These growth factors are expressed in percentage terms and minor fuel consumption in year *y* is simply minor fuel consumption in (*y-1*) multiplied by (1+minor fuel growth rate).

SOURCES:

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

MODEL INPUT: Floorspace vintage

MODEL COMPONENT: Floorspace

DEFINITION: A numerical index varying from 1 to 5 that represents the age range of original construction years for commercial floorspace by building type *b* and Census Division *r*.

DISCUSSION:

The CBECS 1989 data set provides sets of years which are the median values of the original construction ranges. The ranges are defined in the table below.

Building Vintage Range	Median Value of Range
Pre 1945	1921
1946-1959	1952
1960-1969	1965
1970-1979	1975
1980-1989	1985

MODEL INPUT: Cogeneration of electricity by commercial sector facilities

MODEL COMPONENT: End-Use Consumption

DEFINITION: Commercial sector electricity generation by fuel *f* to meet service demand *s* in Census Division *r*

DISCUSSION:

Historical data for commercial sector SIC codes from the EI-867 Survey of Independent Power Producers for the years 1989, 1990, and 1991 forms the basis for the forecast of cogenerated power by fuel and Census Division. The EI-867 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.

The baseline forecast of cogeneration by source fuel is set at 1991 levels with a price sensitivity component that uses the percent changes from the base year electricity prices and generating fuel prices, relative to the AEO 1993 forecast of these prices.

SOURCES:

EI-867, Survey of Independent Power Producers data base

Energy Information Administration, "Nonutility Power Producers," Electric Power Monthly, April 1992.

MODEL INPUT: Office equipment penetration

MODEL COMPONENT: Service Demand

DEFINITION: Office equipment market penetration index by building type and year

DISCUSSION:

The Lawrence Berkeley Laboratory source cited below documents the LBL study performed to forecast office equipment market penetration, including EUIs from 1983, with forecasts to 2011. The market penetration index is set to unity in 1989, and the LBL forecast is indexed to the 1989 base year. The indexed LBL forecast of office equipment market penetration is included in the NEMS Commercial Module calculation of service demand.

The appendix of the LBL report cited below provides estimates for seven types of office equipment:

Mainframes/minicomputers
Personal Computers
Photocopies
Printers
Facsimile Machines
Typewriters

Equipment saturation levels (measured in number of units per 1000 square feet) and the unit energy consumption (UEC in unit kWh per year) estimates from 1983 to the year 2011 are used in the calculation of market penetration performed in the source cited below. The energy use intensities by building type (in kWh per square foot per year) are used to allocated the averages over the building types. The calculations applied to this data prior to its inclusion in the NEMS Commercial Module are described below.

$$\begin{matrix}Total\ Energy\\ Consumption_y\end{matrix} = \sum_s (Saturation_{s,y} \times UEC_{s,y}) \qquad \text{(A-8)}$$

$$\begin{matrix}Average\\ UEC_y\end{matrix} = \frac{Total\ Consumption_y}{\sum_s Saturation_{s,y}} \qquad \text{(A-9)}$$

The average UEC is indexed to the base year 1989, and the saturations are indexed similarly for inclusion in the NEMS Commercial Module.

SOURCE:

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

VARIABLE NAME: Equipment market share

MODEL COMPONENT: Technology Choice

DEFINITION: Current year market share of technology k of vintage v that meets service demand s in building type b in Census Division r.

DISCUSSION:

Base year market shares for the representative technologies included in the technology characterization data base are computed based upon consumption patterns from CBECS 1989. These shares are computed for the major services including space heating, space cooling, water heating, ventilation, cooking, and lighting. Additionally, the average base year efficiencies are calculated by fuel. Both fuel shares and technology market shares are computed for each major service.

Space Conditioning. For example, the percent of the total floorspace heated using electricity as its energy source is computed.

$$Percent\ of\ flsp_{r,s,f} = \frac{Total\ floorspace_{r,s,f}}{\sum_{f=1}^{n} Total\ floorspace_{r,s}} \qquad \text{(A-10)}$$

where,

r is the Census Division,

s is the service category,

f is the energy source or fuel type and

n is the number of possible fuels for the service.

The percent of the total floorspace with the service, fuel type, and equipment type is computed using data from Commercial Building Characteristics as,

$$Percent\ of\ flsp_{r,s,f,t} = \frac{Total\ floorspace_{r,s,f,t}}{\sum_{k=1}^{m} Total\ floorspace_{r,s,f}} \qquad \text{(A-11)}$$

where,

r	is the Census Division,
s	is the service category,
f	is the energy source or fuel type
k	is the equipment type and
m	is the number of possible equipment types for the service.

The market share is then equal to the product of the percent of total floorspace by service and fuel within a region and the percent of floorspace by service, fuel, and equipment or,

$$\begin{matrix} Inital \\ market \\ share_{r,s,f,t} \end{matrix} = \begin{matrix} Percent\ of \\ total\ floorspace_{r,s,f,t} \end{matrix} \times \begin{matrix} Percent\ of \\ total\ floorspace_{r,s,f} \end{matrix} \qquad \text{(A-12)}$$

The above equation provides the calculation for the base year market share. In subsequent years of the forecast, equipment market shares are computed as aggregations of the equipment choices calculated in the Technology Choice Submodule. The efficiencies for each service for a specific fuel are computed as,

$$Efficiency_{r,s,f} = \frac{\sum \dfrac{Efficiency\ by\ equipment}{\begin{matrix} Percent\ of\ total \\ heated\ flsp.\ by\ equipment \end{matrix}}}{No.\ of\ equipment\ types\ using\ fuel} \qquad \text{(A-13)}$$

Water Heating. Base year market shares for water heating equipment are computed from the data obtained from Commercial Buildings Characteristics. Regional floorspace by water heating fuel is divided by total floorspace with water heating within the region. Average equipment efficiencies are taken from the EPRI, NES, and AEO90 sources cited below.

Lighting. Initial market shares for lighting are computed using 1986 NBECS data from Lighting in Commercial Buildings. The shares are computed as,

$$\textit{Initial equipment market share} = \frac{\textit{Flsp. using equipment type}}{\textit{Regional flsp. lighted}} \times \frac{1}{\sum_t \textit{Market shares}_t} \tag{A-14}$$

where k is the equipment type. The regional share is adjusted by the sum of the market shares because some floorspace may be illuminated by two or more types of fixtures.

SOURCES:

U.S. Department of Energy, Energy Information Administration, Commercial Buildings Energy Consumption and Expenditures 1989, Washington, DC, April 1992, p. 50-53.

U.S. Department of Energy, Energy Information Administration, Commercial Buildings Characteristics 1989, Washington, DC, June 1991.

U.S. Department of Energy, Energy Information Administration, Lighting in Commercial Buildings, Washington, DC, May 1992, p. 36-37.

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.

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.

MODEL INPUT: Consumer time preference distribution data

MODEL COMPONENT: Technology Choice

DEFINITION: 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 a given time preference interest rate premium.

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.[1] 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.[2] Each distribution is discrete, consisting of eleven cells, corresponding to the

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

eleven payback years. Finally these are averaged to form a composite distribution.[3]

SOURCES:

Koomey, Jonathan G., "Energy Efficiency Choices in New Office Buildings: An Investigation of Market Failures and Corrective Policies," dissertation, University of California at Berkeley, 1990, 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.

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

[3]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.

MODEL INPUT: Consumer behavior rule proportions

MODEL COMPONENT: Technology Choice

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

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 decisionmakers, 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 Commercial Buildings Characteristics 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.

Department of Energy, Energy Information Administration, Commercial Buildings Characteristics 1989, EIA, Washington DC, June 1991, p. 83.

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.

MODEL INPUT: Commercial sector renewable energy consumption forecast

MODEL COMPONENT: Service Demand

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

DISCUSSION:

A baseline projection for renewable energy consumption developed by the National Renewable Energy Laboratory (NREL) is read into the Commercial Module, since forecasts from the NEMS Renewables Module are not currently available at the level of disaggregation required by the Commercial Module. The NREL forecast for the year y is transformed into service demands using the average efficiency by service for the year y-1 (e.g., the 1997 average space heating efficiency is applied to the 1998 renewable energy consumption, since 1998 end-use consumption is calculated subsequent to the execution of the service demand algorithm). 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. The computation to apportion the contribution into NEMS categorization is,

$$\begin{matrix}\textit{Renewable energy}\\ \textit{for space heatg}\\ \textit{in Census Divis r}\\ \textit{in forecast year y}\end{matrix} = \begin{matrix}\textit{Total solar energy}\\ \textit{for space heatg}\\ \textit{in forecast year y}\end{matrix} \times \left(\frac{\begin{matrix}\textit{CBECS floorspc}\\ \textit{in Census Divis r}\end{matrix}}{\textit{Total CBECS floorspc}}\right) \qquad \textbf{(A-15)}$$

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-867 Survey of Independent Power Producers data base.

SOURCES:

Energy Information Administration, EI-867 Survey of Independent Power Producers 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: Building shell efficiency index

MODEL COMPONENT: Service Demand

DEFINITION: Shell efficiency index for buildings constructed in the current year for building type *b* in Census Division *r* in year *y*.

DISCUSSION:

The 1989 existing stock shell efficiency is indexed to 1.0 by construction. The building shell efficiency index measures the improvement in the shell integrity of newly-constructed floorspace that must by law adhere to building codes in order to be deemed occupiable.

Regional shell efficiency parameters developed from a 1992 Pacific Northwest Laboratory (PNL) study cited below are included in the model. The PNL study consists of an extensive microsimulation of buildings closely matching the CBECS 1989 building types across the country. The PNL study analyzes the impacts on shell efficiency based upon three groups of buildings: those built to 1980 building codes, those built to 1992 building codes, and future potential buildings built to forecasted 1993 building codes. Regional data from the PNL study enables regional proportions to be included in the model. The model currently does not incorporate assumptions regarding the proposed 1998 efficiency standards that may impact future building codes.

SOURCES:

Koomey, J., Lawrence Berkeley Laboratory, personal communication, June 18, 1992.

Pacific Northwest Laboratory, personal communication with R. Jarnagin, August, 1992.

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

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MODEL INPUT: Floorspace survival function parameter

MODEL COMPONENT: Floorspace

DEFINITION: Shape parameter for the floorspace survival function.

DISCUSSION:

The floorspace survival function parameter is calculated by substitution of average building lifetime values into the survival function equation until the functional results are such that one-half of the original floorspace stock remains at the midpoint of the documented average building lifetime and the documented percentage of buildings remaining one year after construction is also obtained. The computation is based on the floorspace survival function,

$$\textit{Survival Rate} = \frac{1}{1+\left(\dfrac{\textit{current year} - \textit{building vintage year}}{\textit{average age}}\right)^{\textit{building survival parameter}}} \qquad \textbf{(A-16)}$$

so that, when the bracketed term in the denominator is unity (i.e., the buildings in the age range under consideration reach the average building lifetime), the survival rate is 0.5 by design. The calculation in Equation A-16 yields the survival rate along the curve determined by the average age, the percentage of buildings remaining one year after construction, and the selection of the building survival parameter. Average building lifetimes are given by the DRI Macroeconomic Module that drives the NEMS Macroeconomic Activity Module.

MODEL INPUT: Short-term price elasticity of service demand

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.

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.

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 Distlat.	-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.

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Appendix B. Mathematical Description

Scope of this Appendix

This Appendix provides supporting discussions for the mathematical description of the NEMS Commercial Module provided in the main text (Chapter 4) of Volume I of this report. This Appendix is arranged by Submodule, encompassing the Floorspace, Service Demand, Technology Choice, End-Use Consumption, and Benchmarking Submodules that comprise the NEMS Commercial Module. The equation references provided in this Appendix refer to the equation numbers in Chapter 4 of the main text of Volume I.

The discussion provided in Chapter 4 is extensive and is based directly upon the FORTRAN source code that generates the NEMS Commercial Module results. Therefore, the supporting material provided in this Appendix is brief.

Floorspace Submodule

The numerator in the right-side term in Equation (4-1) is the CBECS 1989 existing floorspace stock. The denominator of this term is the survival fraction calculated as described in Chapter 4 of the main text. The MC_COMMFLSPC variables included in Equation (4-3) are directly input from the NEMS Macroeconomic Activity Module (MAM) forecast. The DRIBldgRetireRate in Equation (4-3) is the building retirement rate assumed by Data Resources Inc. (DRI), the contractor responsible for the development of the MAM floorspace forecast. The DRItoCBECS conversion factors referenced in Equation (4-4) are developed by mapping the DRI floorspace categories to the CBECS 1989 floorspace categories used in the NEMS Commercial Module.

Service Demand Submodule

Service Demand Submodule

The ServDmdInten variables referenced in Equations (4-5) and (4-6) are developed from the Energy-Use Intensity (EUI) estimates based on CBECS 1989 consumption data. The ShellEffIndex variables referenced in these two equations are developed from prototypical building analysis performed to determine the impacts on shell efficiency in the presence of building standards. The study performed to estimate these impacts is cited in Appendix C. As described in the Fundamental Assumptions section of Chapter 3 of the main text, office equipment market penetration (OfficeEquipMktPen) is required in order to forecast office equipment service demand, since the module assumes that this service is not yet saturated.

The district service share inputs (DistrictHeatShare) in Equations (4-11) and (4-12) are applied to calculated service demand in order to appropriately decrement the service demand that requires equipment competition in the Technology Choice Submodule, since some of the service demand that would otherwise be competed is currently met through district systems. A similar explanation is applicable for the accounting of the solar renewable energy contribution toward meeting service demand that would otherwise require technology competition (Equations (4-13) and (4-14)).

The price elasticity of service demand calculations are included on a composite, fuel share-weighted basis to account for price responsiveness in the service demand level, and the fact that the module allows fuel switching.

Technology Choice Submodule

Equation (4-21) calculates the annualized technology cost as the sum of three components: annualized installed unit capital cost, annual operating and maintenance cost, and annual fuel cost. The first component accounts for the operating profile of the equipment by Census

Division, building and service, through the CapacityFactor term. The consumer time preference premium is also considered in this component. The third component of this equation calculates annual fuel costs as a function of the expected lifetime of the technology (TechLife) and the technology performance factor (TechEff), in order to account for the variation in expected performance and lifetime across technology choices.

The market share calculations are based on the distribution of values of the logical variables that rank the annualized technology costs calculated in Equation (4-21). The retrofit calculations in Equations (4-30) through (4-35) account for the consumer option of retaining existing equipment at zero incremental capital cost.

End-Use Consumption Submodule

The equations that comprise the End-Use Consumption Submodule primarily perform aggregations of the results obtained in the Technology Choice Submodule. Equations (4-51) through (4-55) utilize the fuel shares of service demand (FuelShrServ) and average equipment efficiency (AverageEfficiency) results of the technology selections to transform calculated service demands into end-use consumption values. Since end-use consumption is only a subset of total commercial sector consumption, additional calculation in the Benchmarking Submodule is required.

The other significant operations performed in the End-Use Consumption Submodule comprise the calculation of commercial sector electricity cogeneration (Equations (4-58) through (4-60). The CMBaselineElCogen term in Equation (4-58) represents the baseline electricity cogeneration forecast for the commercial sector, and is based upon historical data from the EI-867 data collection form. The growth factor for the baseline forecast, CMCogenGrowthFactor, is also based on the EI-867 data. Further discussion of the cogeneration forecast procedure is provided in Appendix A (see Table A-2 for reference).

Benchmarking Submodule

The energy demand results calculated in the End-Use Consumption Submodule are based upon commercial building energy consumption choices. The goal of benchmarking is to account for commercial sector consumption not attributable to commercial buildings. The scope of the SEDS includes nonbuilding energy sources, and therefore, SEDS is used as the reference value for the base year of 1990. Equations (4-64) through (4-65) link the module results (based upon end-use consumption in commercial buildings) with the historical SEDS consumption values (including nonbuilding commercial sector consumption) for the year 1990, and calculate the growth rate path (through the module input CMNonBldgGrowth) for nonbuilding consumption. Airborne emissions attributable to commercial sector activity are calculated in Equation (4-66), based on emissions factors described in Appendix A (see Table A-2 for reference to emissions factor calculation).

Appendix C. References

Introduction

This Appendix provides a bibliography citing literature used in the theoretical and analytical design, development, implementation, and evaluation of the NEMS Commercial Module. The references supplied here are supplemented by additional detail regarding page citations, both in the body of this report and in the references provided in Appendix A, starting at Table A-1.

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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, 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, refrigeration, and "other" in less detail than the major fuels and 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:

November 1994.

Part of Another Model?

National Energy Modeling System (NEMS)

Model Interfaces:

Receives inputs from the Electricity Market Module, Oil and Gas Market Module, Renewable Fuels Module, and Macroeconomic Activity Module within NEMS. Outputs are provided to the Electricity Market Module, Oil and Gas Market Module, and Integrating Module.

Official Model Representative:

Erin E. Boedecker
Office of Integrated Analysis and Forecasting
Energy Demand and Integration Division
Energy Demand Analysis Branch
(202) 586-4791

Documentation:

Model Documentation Report: Commercial Sector Demand Model of the National Energy Modeling System, February 1995.

Archive Media and Installation Manual(s):

The Module will be archived on IBM3380 tape compatible with the IBM 3090 mainframe system upon completion of the NEMS production runs to generate the Annual Energy Outlook for 1995 (AEO95).

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 2015
- 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. Nine Services: Space Heating, Space Cooling, Water Heating, Ventilation, Cooking, Lighting, Office Equipment, Refrigeration, Other.

Modeling Features

- Model Structure: Sequential calculation of forecasted commercial floorspace, service demand, 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 1989 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

- Historical commercial sector floorspace by Census Division and building type, for the years 1970-1990
- Historical floorspace retirement proportion by Census Region for the year 1990
- 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

- Historical commercial sector floorspace by Census Division and building type, for the years 1970-1990
- Historical floorspace retirement proportion by Census Region for the year 1990
- 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 1986-1993
- Equipment research and development (R&D) advances and projected dates of model introduction, projections for technology availability encompassing the years 1995-2010

DOE Input Sources:

Commercial Building Energy Consumption Survey 1989 (CBECS 1989)

- 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-867: Survey of Independent Power Producers, forms for years 1989-1991

- 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.

National Renewable Energy Laboratory (NREL) Interlaboratory Documentation, 1990

- Forecasted commercial sector renewable energy demand, by renewable source and energy service

Computing Environment:

- Hardware Used: IBM 3090
- Operating System: MVS
- Language/Software Used: VS FORTRAN, Ver. 2.05
- Memory Requirement: 4,000K
- Storage Requirement: Model has not yet been archived. It will require an as-yet undetermined number of tracks of an IBM 3380 disk pack
- Estimated Run Time: 3.5 minutes for a 1990-2015 run in non-iterating NEMS mode on an IBM 3090
- Special Features: None.

Independent Expert Reviews Conducted:

Independent Expert Reviews of *Commercial Sector Component Design Report, July 31, 1992* conducted by David Belzer, Pacific Northwest Laboratory; Richard E. Jones, Office of Building Technologies, Conservation and Renewable Energy; James E. McMahon, Ph.D., Lawrence Berkeley Laboratory; Robert P. Trost, Ph.D., and Inderjit Kundra, Office of Statistical Standards.

Status of Evaluation Efforts by Sponsor:

None.

Appendix E. Data Quality

Introduction

The NEMS Commercial Sector Demand Module develops 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 1989 (CBECS 1989)

EIA's Commercial Buildings Energy Consumption Survey 1989 (CBECS 1989) is the principal data source for the NEMS Commercial Module forecast of energy consumption. This section discusses the quality of the CBECS 1989 data set as described in Commercial Buildings Consumption and Expenditures 1989[1].

CBECS 1989 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 Commercial Buildings Consumption and Expenditures 1989.

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1 U.S. Department of Energy, Energy Information Administration, Commercial Buildings Consumption and Expenditures 1989, DOE/EIA-0318 (89), pp. 275-359.

Consumption and Expenditures 1989.

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 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 1989 samples 8,791 buildings, selected based upon an area probability sample supplemented by lists of large 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 1989 sample does not overlap with previous CBECS. Primary differences between the CBECS 1989 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 1989 is domestic commercial buildings greater than 1,000 ft^2 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^2 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 1989 is 8,791 buildings, composed of 6,659 from the area sample and 2,132 from a list sample. Of these, 6,352 buildings are interviewed, 4,770 from the area sample and 1,582 from the list sample. Successful interviews for 92.5% of the eligible buildings (5,277) are contained in CBECS 1989. Similar success rates for Authorization Form completion are observed in the sample.

Data Collection. As previously described, the Buildings Characteristics Survey consists of personal interviews with buildings' owners, managers, and tenants. A limited number of these interviews are telephone interviews, either due to a nonresponse conversion effort or lack of access to a building representative in the same PSU as the site. In all cases, a physical site visit is included.

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, 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.

Completed questionnaires are edited twice, in conjunction with random sample validation of 17% of respondents by supervisory personnel. 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 1989. 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 86.7%. 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 form to natural gas and electric suppliers that were previous CBECS participants is one facet of the data collection effort. This form reported the results of CBECS 1986, alerted suppliers that a 1989 effort would soon commence, and requested notification of updates to supplier information. Second, prenotification was followed by mailed survey forms to energy suppliers based upon Stage I response patterns from the Building Characteristics Survey. The third facet of the Stage II effort consists of thank-you letters mailed to participants and requests for feedback regarding survey procedures, to be incorporated in future CBECS surveys.

Data Quality Verification. At the conclusion of the input and editing procedure, additional data quality verification consists of the following steps:

- A manual review of the completeness of the discrete fuel sources, including review of sporadic records;
- A comparison of energy-source record accounts with the number of energy sources indicated for the building by the building respondent;
- A comparison of prices for standardized quantities with all bill records to detect price errors;
- An identification process through a program to flag overridden data written to the file in error, accompanied by review of these errors.

This process ensures the quality of the CBECS 1989 input data, which is the principal source of initial floorspace levels and age cohorts, appliance stock composition, district service shares, and unbenchmarked 1989 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 preliminary results generated in advance of the November 1993 study published by Pacific Northwest Laboratory (PNL) and referenced in Appendix C of this report. Data quality issues are addressed in the PNL report, specifically related to sampling considerations and the appropriate level of statistically significant disaggregation.

Technology Characterization Data Sources

The EPRI, Arthur D. Little, and GRI data sources used to develop technology characterization profiles for the NEMS Commercial Module do not provide discussions of data quality. The EIA report, Lighting in Commercial Buildings[2] provides extensive discussion of the quality of the data used to develop lighting equipment profiles.

Historical Energy Consumption Data: State Energy Data System (SEDS), 1990

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[3]

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[2] U.S. Department of Energy, Energy Information Administration, Lighting in Commercial Buildings, DOE/EIA-0555(92)/1, March 1992, pp. 72-88.

[3] U.S. Department of Energy, Energy Information Administration, State Energy Data Report, Consumption Estimates: 1960-1990, DOE/EIA-0214(90), May 1992, pp. 437-461.

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 eleven time preference premium segments and three behavior rules described in the body of this report. The time preference premiums are developed based on analysis of survey and utility data as described below. The behavior rules represent the proportion of consumers following the Least Cost, Same Fuel, and Same Technology rules. These parameters are designed to be calibration parameters, and as such are available to align model results with observed historical consumption results and professional expectations.

The initial behavior rule proportions are estimated by building type and decision type in order to create relationships between the different types of decisionmakers and different types of decisions. For existing buildings (replacement and retrofit decision types), the decisionmakers are divided into government, private sector companies occupying self-owned building space, and private sector companies occupying rented building space. For new buildings, decisionmakers 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 with 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 the associated consumer preference premiums were averaged 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 Preference Premium Distribution

Percent of Commercial Sector Consumers	Commercial Consumers' Time Preference Premium to the Risk-Free Interest Rate
12.4 %	∞
14.4 %	152.9 %
16.4 %	55.4 %
19.2 %	30.9 %
19.6 %	19.9 %
10.4 %	13.7 %
3.4 %	9.4 %
1.2 %	6.4 %
1.0 %	4.5 %
1.0 %	2.9 %
1.0 %	1.5 %

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 Consumer 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 ∞

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.

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	20.4 %	74.8 %	4.8 %
Education	77.5 %	22.4 %	0.2 %
Food Sales	0.6 %	77.0 %	22.3 %
Food Service	9.3 %	79.9 %	10.8 %
Health Care	24.1 %	70.9 %	5.0 %
Lodging	17.9 %	72.4 %	9.7 %
Mercantile/Service	3.2 %	64.6 %	32.2 %
Office	19.9 %	56.3 %	23.8 %
Warehouse	6.5 %	63.4 %	30.1 %
Other	22.2 %	44.4 %	33.4 %
TOTAL:	22.0 %	57.4 %	20.6 %

References

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.

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.

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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, Lighting in Commercial Buildings, DOE/EIA-0555(92)/1, March 1992.

U.S. Department of Energy, Energy Information Administration, State Energy Data Report, Consumption Estimates: 1960-1990, DOE/EIA-0214(90), May 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.

Appendix F: Model Sensitivities

Solution Methodology

The NEMS Commercial Module simulates the behavior of commercial energy consumers through a dynamic flow process. A sequential calculation of floorspace, service demand, and technology choice is employed to yield estimates of end-use consumption. The mathematical equations provide meaningful results because of the detail level of the input for each submodule and the modeling approach chosen.

Theoretical Considerations

Domain of Module Solution

The module is a sequential structured algorithm that solves recursively. The domain of the solution is all positive values for the solution variables of commercial sector fuel consumption by Census Division, building type, fuel and year; and commercial sector airborne emissions by pollutant and year. In addition, the intermediate module outputs of interest to the Load and Demand Side Management Submodule (LDSM) of the NEMS Electricity Market Module (EMM), specifically the fuel proportions of service demand and marketplace equipment performance characteristics calculated in the Technology Choice Submodule of the Commercial Module, also assume positive values.

Module Stability

A frequently employed method of model assessment is to investigate output response to a variety of different input data and parameter assumptions. The structure of the model should be such that the output responds in a manner that reflects the underlying physical and behavioral tenets of the model. This implies that reasonable changes in inputs do not cause catastrophic model results indicating a structural flaw in the model design. This section presents the input parameters for each Submodule of the NEMS Commercial Module. A realistic range for each parameter is discussed as well as extreme and counter-factual parameter values. Because the effects of each parameter ultimately affect the final output of the module, in some cases changes to user inputs can result in numerous conflicting impacts of unknown relative magnitudes, rendering the final outcome on final energy consumption unclear.

Commercial Module Empirical Basis

This section presents **preliminary** module results. The empirical basis of the Commercial Module is initially reviewed by comparing results to historical data and the forecasts produced by the Department of Energy and alternative sources. In order to analyze module stability, numerous scenarios in which key input values and assumptions vary are also presented. It must be emphasized that the forecasts presented in this Module Developer's Report are **preliminary** and are not the official EIA forecasts. These forecasts are used only for examining the responsiveness of the NEMS Commercial Module.

In order to place the NEMS forecast in perspective, some inspection of the historical trends of consumption should be considered. Figure 1 extrapolates the historical values of total commercial energy consumption data reported in the State Data Energy System (SEDS). For comparison, Figure 1 includes the preliminary NEMS forecast. The historical data shows an upward trend in aggregate consumption. The NEMS forecast continues this upward trend and is slightly higher than the SEDS projection.

The NEMS forecast of commercial electricity consumption evenly continues the historical consumption path over the forecast horizon. Figure 2 displays the time path of the consumption along with NEMS forecasts and a naive extrapolation of the historical SEDS data. The historical series displays very stable growth in consumption with relatively little variation. In addition, the NEMS forecast lies below the linear extrapolation of the SEDS data.

The historical consumption of natural gas in the commercial sector is depicted in Figure 3. Natural gas projections display greater variation than either total or electricity consumption. As apparent in Figure 3, the NEMS forecast continues the rising trend in consumption

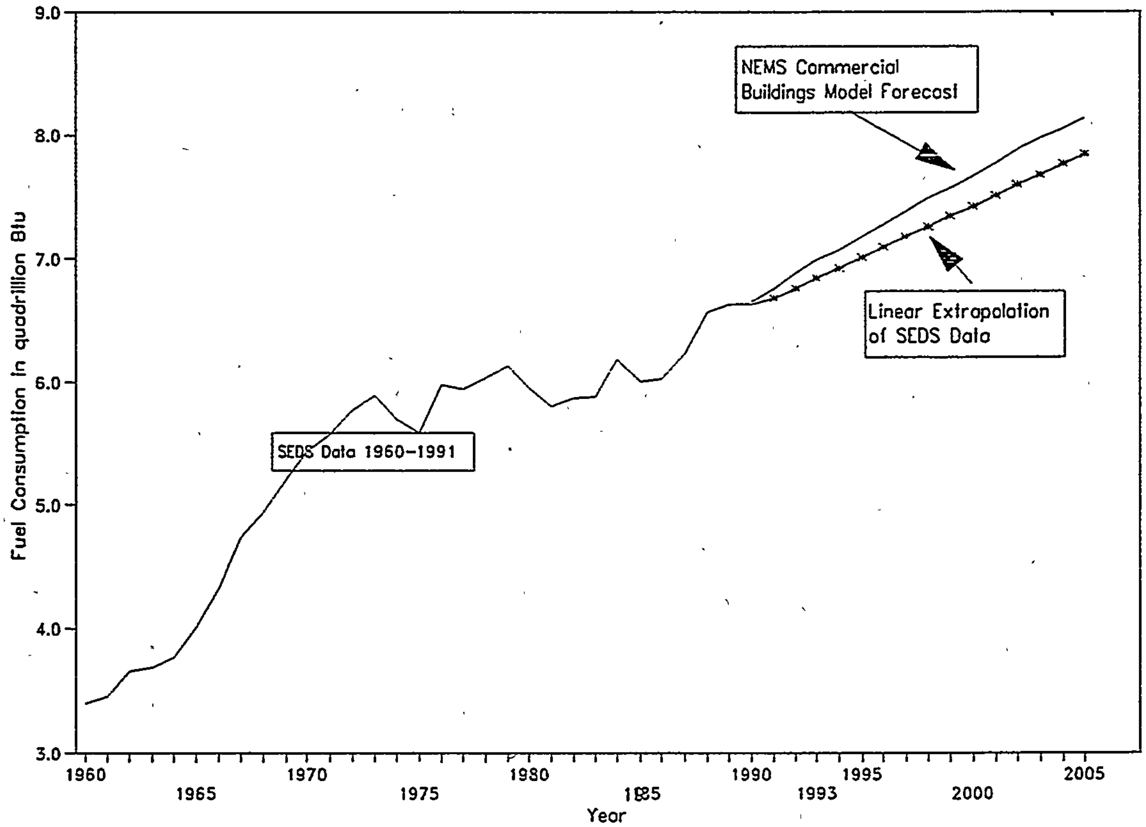

Figure 1. Total Energy Consumption: SEDS and NEMS

throughout the forecast horizon, although it is lower than the linear extrapolation of SEDS.

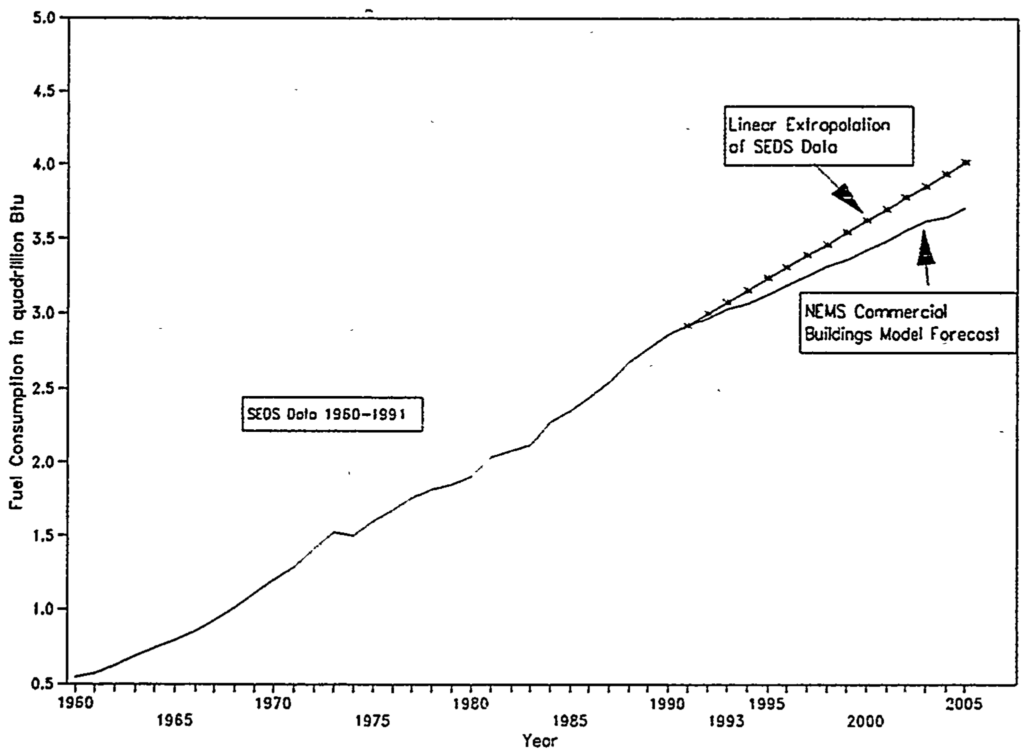

Figure 2. Commercial Sector Electricity Consumption: SEDS and NEMS

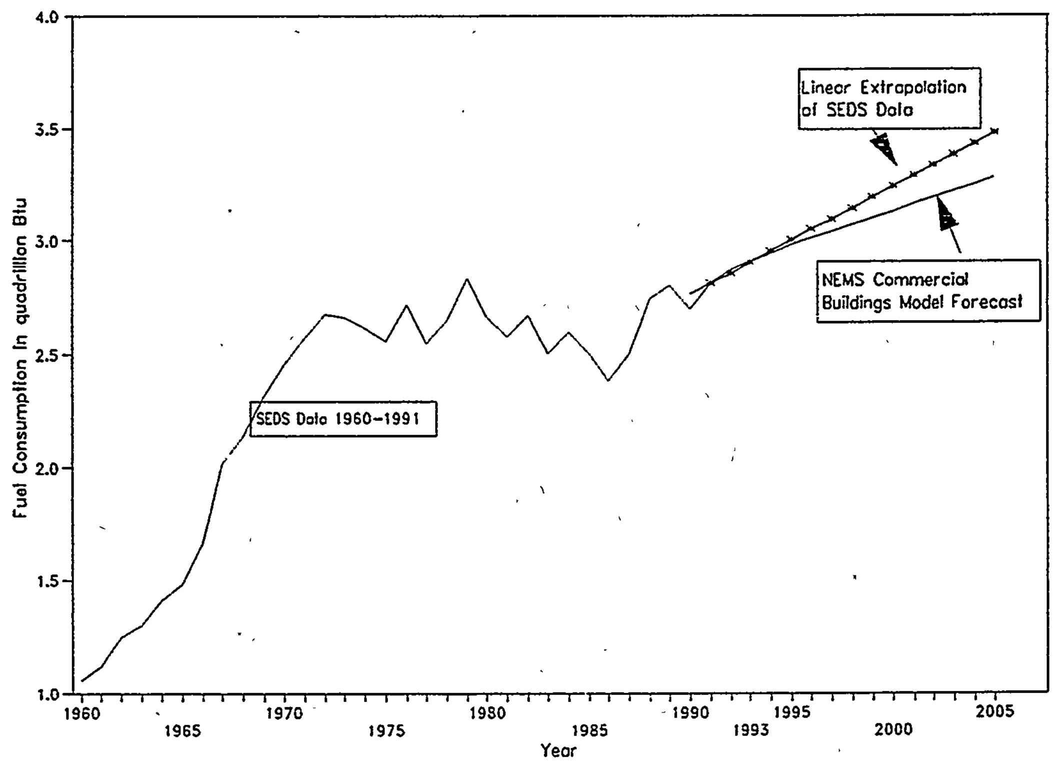

Figure 3. Commercial Sector Gas Consumption: SEDS and NEMS Comparison with the Annual Energy Outlook 1993

The AEO93 is the most recent commercial energy demand forecast prepared by EIA. This section compares the preliminary NEMS forecast with the AEO93 forecast as well as the Wharton Econometric Forecasting Associates Group (WEFA) forecast and DRI/McGraw-Hill (DRI) forecast. The AEO93 forecasts were developed using the BEEM Model.[1] WEFA and DRI have developed and maintained integrated modeling systems. The NEMS forecasts presented in this

[1] Energy Information Administration, *PC-AEO Forecasting Model for the Annual Energy Outlook 1990, Model Documentation*, DOE/EIA-036(90), March 1990.

section are **preliminary**, and are presented to illustrate a frame of reference for the module and the likely range of the final AEO94 forecasts.

Table 1 contains a comparison of the available forecasts for the commercial sector. In 1995, NEMS forecasts 7.18 quads compared to 7.42 in the AEO93 for a difference of 0.24 quads or 3.2%. The NEMS forecast rises to 8.55 quads for the year 2010 compared to AEO93's reference case of 8.27 quads for a difference of 0.28 quads or 3.4%. The DRI forecast is consistently lower than either the NEMS or AEO93 forecasts. The DRI aggregation of energy demand in the commercial sector may not be comparable to the definitions used by EIA. WEFA forecasts increase more rapidly than either NEMS or the AEO93 cases. Figure 4 illustrates the forecasts for total energy demand in the commercial buildings sector for the forecast horizon 1995 to 2010. The WEFA projection reaches 8.75 quads by the year 2010 while the NEMS forecast is 8.55 quads, a divergence of 0.20 quads from the NEMS forecast. The difference in forecasts of total energy demand is partly attributable to differing fuel price forecasts as discussed in further detail in this section.

Table 1. Forecast Comparison: Commercial Sector Energy Demand by Fuel: Quadrillion Btu

Electricity Forecasts

	1995	2000	2005	2010
NEMS	3.13	3.43	3.71	3.92
AEO93 High Economic Growth	3.12	3.42	3.68	3.88
AEO93 Reference Case	3.12	3.40	3.64	3.83
AEO93 Low Economic Growth	3.12	3.38	3.61	3.77
WEFA	3.12	3.40	3.73	4.07
DRI	3.12	3.39	3.64	3.85

Natural Gas Forecasts

	1995	2000	2005	2010
NEMS	2.98	3.13	3.28	3.44
AEO93 High Economic Growth	3.07	3.18	3.26	3.31
AEO93 Reference Case	3.08	3.17	3.23	3.25
AEO93 Low Economic Growth	3.07	3.15	3.20	3.20
WEFA	3.00	3.13	3.36	3.58
DRI	3.08	3.17	3.23	3.32

Distillate Fuel Forecasts

	1995	2000	2005	2010
NEMS	0.53	0.57	0.60	0.62
AEO93 High Economic Growth	0.57	0.53	0.49	0.45
AEO93 Reference Case	0.57	0.53	0.49	0.44
AEO93 Low Economic Growth	0.57	0.53	0.48	0.44

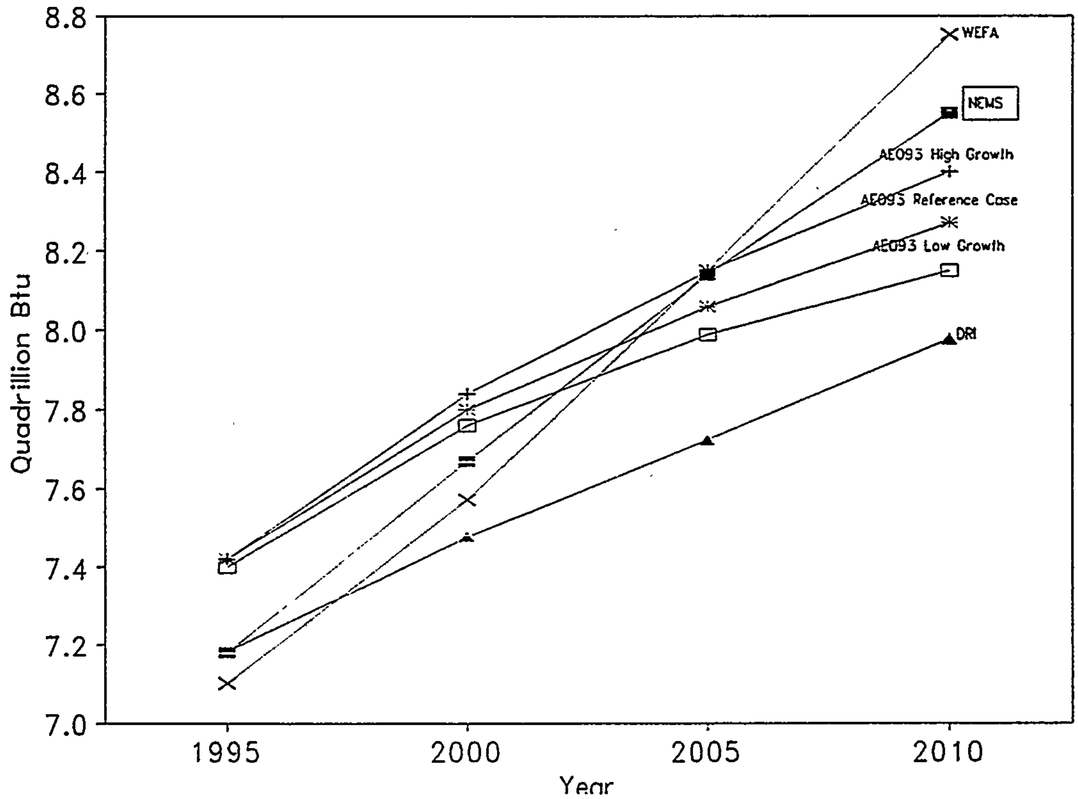

Figure 4. Forecasted Commercial Sector Energy Demand

Forecasts by major fuel are compared in Table 1. The distillate fuel forecasts rises in the NEMS forecast from 0.49 to 0.64 quads and falls in the AEO93 reference forecast from 0.49 to 0.44 quads.

Electricity forecasts display more similar projected trends, as evident in Figure 5. The NEMS forecast projects 3.92 quads in 2010. This projection is higher than the AEO93 scenarios and the DRI forecasts, although the forecasted fuel prices are significantly different for each of these projections. The AEO93 reference case prices for electricity rise from $19.94/MMBtu in 1990 to $20.19/MMBtu in 2010, while the NEMS electricity prices fall over the same period from $20.69/MMBtu to $19.52/MMBtu. The DRI electricity price forecast falls over the 1990 to

2010 period from $23.84/MMBtu to $20.07/MMBtu as well. This price forecast may explain the comparability of the DRI forecast and the NEMS forecast. In general, falling electricity prices and constant (or increasing) prices for alternative fuels should increase electricity demand. Therefore, none of these forecasts appear to contradict with basic economic intuition.

Figure 6 suggests that natural gas demand forecasts diverge more drastically than the electricity demand forecasts. The NEMS module forecasts natural gas demand of 3.44 quads in 2010 as compared to the reference case AEO93 forecast of 3.25 quads. The NEMS forecast displays an increasing trend in natural gas consumption, as do the WEFA and DRI forecasts while the AEO93 scenarios show consumption leveling off after 2005.

The NEMS natural gas consumption is rising because more attractively priced, high efficiency gas equipment becomes available over the forecast horizon and because gas penetration rises due to behavior rule assumptions and displacement of distillate fuel consumption.

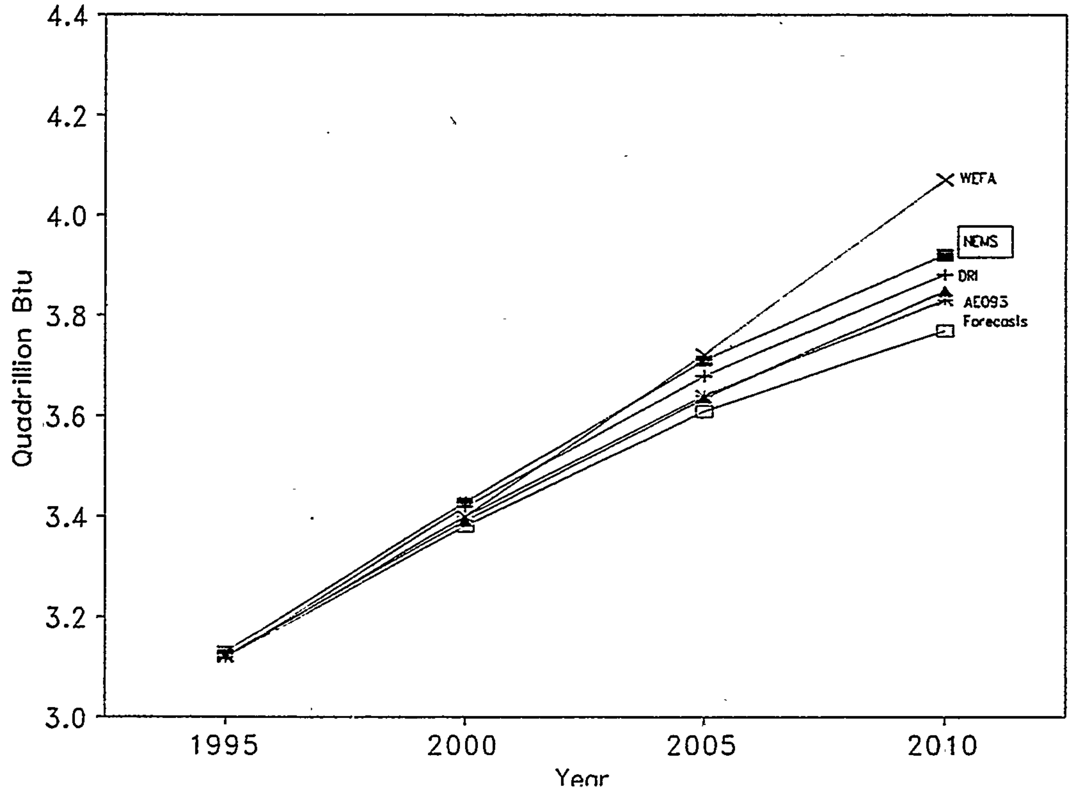

Figure 5. Comparison of Forecasted Commercial Sector Electricity Demand

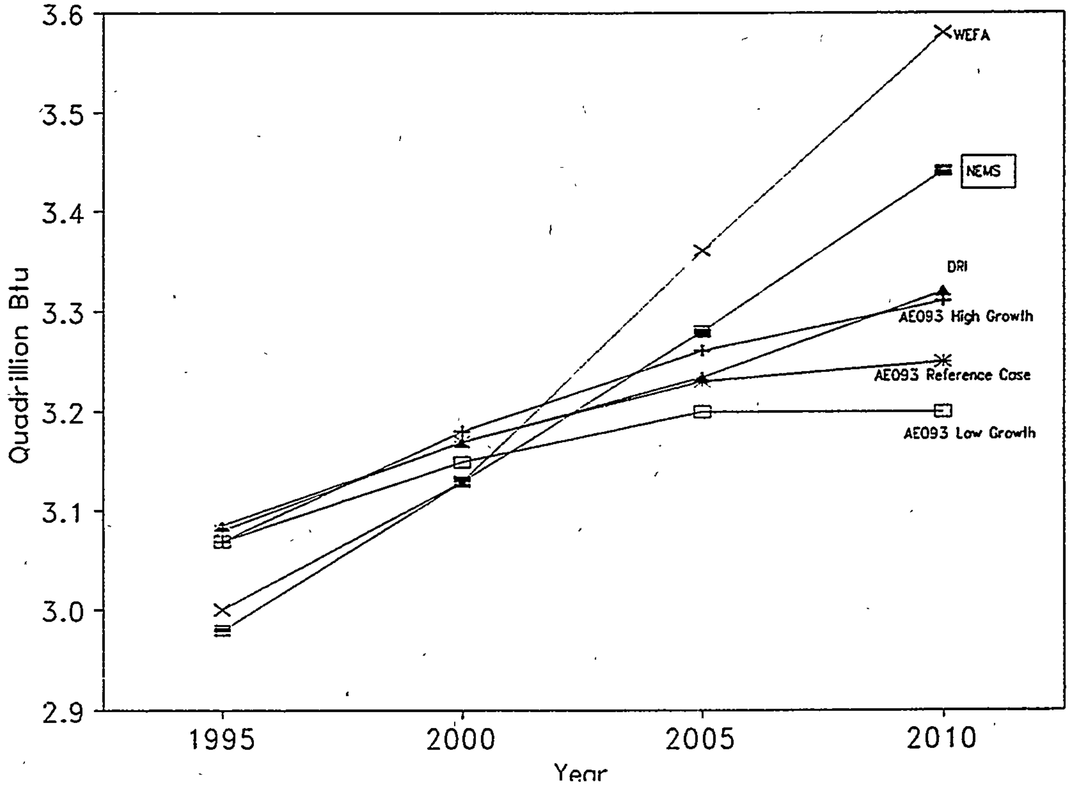

Figure 6. Comparison of Forecasted Commercial Sector Natural Gas Demand

One-at-a-time Module Sensitivity Analysis

The NEMS Commercial Module is composed of five Submodules as described in the Module Documentation Report: Floorspace, Service Demand, Technology Choice, End-Use Consumption, and Benchmarking. The five submodules are executed sequentially in the order presented, and the outputs of each submodule are inputs to subsequently executed submodules. As a result, key forecast drivers for the Floorspace submodule are key drivers for the Service Demand submodule, etc. This section examines the module's responsiveness to a range of changes in economic activity, input prices, and assumptions regarding the behavior of commercial consumers.

The exogenous forecast of commercial floorspace provided by the NEMS Macroeconomic Activity Module (MAM) is the primary driver of the floorspace submodule. Projected floorspace, along with year to year changes in the composition of the stock by Census Division and building type, determine the size and energy-consuming characteristics of the commercial buildings sector.[2] The key output of the Floorspace Submodule is projected commercial floorspace by Census Division, building type, and floorspace category for new, retiring, and surviving buildings.

The projections calculated in the Floorspace Submodule are utilized to develop service demands by Census Division, building type, and service. This direct linkage between the Floorspace and Service Demand Submodules ensures that projected changes in the characteristics of the floorspace stock are reflected in calculated service demands.

As described in the Module Documentation Report, the Technology Choice Submodule calculates the results of the capital stock decisions for the major fuels of electricity, natural gas, and distillate fuel, for the current year of the forecast. Capital stock decisions are driven by commercial

[2] Energy Information Administration. *Component Design Report Commercial Sector Energy Demand.* prepared by Decision Analysis Corporation of Virginia, Contract No. DE-AC01-92EI21946, January 20,1993.

consumer behavioral rule assumptions, fuel prices, relative individual technology capital costs and operating and maintenance (O&M) costs. The primary outputs of the Technology Choice Submodule are the market shares of service demand met by each available technology, and the corresponding average equipment coefficient of performance by (end-use) service.

End-use consumption is developed using the calculated service demands from the Service Demand Submodule, along with the market share and equipment characteristic outputs of the Technology Choice Submodule. End-use consumption is then benchmarked to known historical data for the commercial sector, in order to account for nonbuilding use and other energy consumption that is not modeled within the buildings component.

As described previously, commercial floorspace, fuel prices, and behavioral rule assumptions are key drivers of the module. Sensitivity analysis is therefore focused upon testing module responsiveness under varying assumptions regarding these key drivers. Table 3 summarizes the scenario descriptions that are presented in this report.

Table 2. Scenario Descriptions for Sensitivity Analysis

Scenario Title	Scenario Description
1. Reference Case	Base scenario: NEMS Macroeconomic Activity Module default floorspace, NEMS default fuel prices (BASE92), NEMS Commercial Buildings Model default behavioral rule assumptions
2. High Floorspace	Increase commercial sector floorspace by 10% each year of the forecast. Use Reference Case defaults fuel prices and behavioral rule assumptions
3. Low Floorspace	Decrease commercial sector floorspace by 10% each year of the forecast. Use Reference Case default for fuel prices and behavioral rule assumptions
4. High Electricity Price	Increase commercial sector electricity price by 10% each year of the forecast. Use Reference Case defaults for floorspace, additional fuel prices, behavioral rule assumptions
5. Low Electricity Price	Decrease commercial sector electricity price by 10% each year of the forecast. Use Reference Case defaults for floorspace, additional fuel prices, behavioral rule assumptions
6. Extreme Electricity Price (High)	Quadruple commercial sector electricity price each year of the forecast. Use Reference Case defaults floorspace, additional fuel prices, behavioral rule assumptions
7. Extreme Electricity Price (Low)	Decrease commercial sector electricity price by 75% each year of the forecast. Use Reference Case defaults for floorspace, additional fuel prices, behavioral rule assumptions
8. High Natural Gas Price	Increase commercial sector natural gas price by 10% each year of the forecast. Use Reference Case defaults for floorspace, additional fuel prices, behavioral rule assumptions
9. Low Natural Gas Price	Decrease commercial sector natural gas price by 10% each year of the forecast. Use Reference Case defaults for floorspace, additional fuel prices, behavioral rule assumptions
10. High Distillate Price	Increase commercial sector distillate price by 10% each year of the forecast. Use Reference Case defaults for floorspace, additional fuel prices, behavioral rule assumptions
11. All Least Cost Capital Decisions	Set behavioral rule proportions to 1.00 for Least Cost, 0.00 for Same Fuel and Same Technology Rules. Use Reference Case defaults for floorspace and fuel prices
12. All Same Fuel Capital Decisions	Set behavioral rule proportions to 1.00 for Same Fuel, 0.00 for Least Cost and Same Technology Rules. Use Reference Case defaults for floorspace and fuel prices
13. All Same Technology Capital Decisions	Set behavioral rule proportions to 1.00 for Same Technology, 0.00 for Least Cost and Same Fuel Rules. Use Reference Case defaults for floorspace and fuel prices

Reference Case Scenario

The Reference Case scenario employs the MAM default floorspace forecast, the NEMS Restart File fuel price series, and the NEMS Commercial Module default assumptions for all remaining module parameters, including behavioral rule proportions.

The Reference Case forecast of total commercial floorspace is projected to increase annually, beginning with an annual rate of increase of 1.7%, and tapering off to an annual growth rate of 0.8% by the end of the forecast period. Census Division-specific floorspace trends are more volatile than national floorspace trends, especially in the Mountain Census Division, which accelerates to an annual growth rate of 6.7% by 2015. The floorspace forecast is presented in tabular format in Appendix A to this Module Developer's Report.

Reference Case fuel prices vary relative to each other throughout the forecast period. Initially, the price of distillate fuel is greater than the price of natural gas (measuring all fuels in 1990 dollars/million Btu for equivalence), but this relationship reverses over the forecast period. Forecasted electricity prices fall gradually through 2000, and rise slightly after 2000, for an average annual growth rate of 0.2% over the forecast period. Reference Case fuel prices are provided in Appendix A to this Module Developer's Report.

Reference Case projections of service demand fuel proportions are presented in Appendix A of this Module Developer's Report, and, as described previously, fuel prices are key drivers in the capital stock decision process modeled in the Technology Choice Submodule. The observed changes in the fuel proportions of service demand reflect changes in the relative fuel price series over the forecast period. As anticipated, market equipment performance for the major services of space heating, space cooling, and water heating improves over the forecast period, reflecting the implementation of energy efficiency standards and the gradual trend of the commercial market --

equipment manufacturers and commercial consumers -- toward the installation of higher efficiency equipment.

The initial behavioral rule assumptions indicate that differing proportions of commercial consumers both across and within building types and decision types (new, replacement, or retrofit) consider characteristics of their existing equipment (type of fuel used or type of equipment), in addition to equipment costs, in the capital decision-making process.

Reference Case projections of energy consumption by fuel type are presented in these forecasts, electricity consumption increases from 2.9 quadrillion Btu (quads) in 1990 to 3.3 quads in 2015, for an average annual growth rate of 0.6% over the forecast period. Natural gas consumption increases from 2.8 quads in 1990 to 3.3 quads in 2015, resulting in 0.7% average annual growth over the twenty-five years. Distillate consumption remains at 0.5 quads over the forecast period.

Alternate Floorspace Scenarios

The alternate floorspace scenarios employ the BASE92 NEMS Restart File fuel price series, and the NEMS Commercial Module default assumptions for all remaining user inputs, including behavioral rule proportions. The incremental floorspace scenario increases the MAM floorspace forecast by 10% for each year of the forecast period. The decremented floorspace scenario decreases the MAM floorspace by 10% for each year of the forecast.

Incremented Floorspace Scenario

Appendix B to this Module Developer's Report contains the floorspace forecast employed for this scenario. The expected result of increasing commercial floorspace is increased energy consumption projections for all fuels, since increasing floorspace effectively expands the commercial sector market for all fuels. This expectation is realized, as demonstrated in the energy consumption forecasts. In this consumption forecast, electricity demand rises from 2.9 quads in 1990 to 3.4 quads in 2015, an increase of 0.1 quads over the reference electricity forecast. Similarly, natural gas demand rises from 2.76 quads in 1990 to 3.5 quads in 2015, an increase of 0.2 quads over the Reference Case. Distillate fuel demand falls from 0.5 quads in 1990 to 0.4 quads in 2015, as compared to a steady reference forecast. This last trend reflects the decline of distillate fuel penetration in new commercial floorspace.

Decremented Floorspace Scenario

The decremented floorspace forecast is also provided in Appendix B to this Module Developer's Report. The primary expected result of decreasing commercial floorspace is a corresponding decrease in energy consumption compared to the Reference Case, since decreasing floorspace effectively reduces the size of the commercial market. This expectation is realized, as demonstrated in the energy consumption forecasts. In this consumption forecast, electricity demand rises from 2.9 quads in 1990 to only 3.1 quads in 2015, 0.2 quads less than the reference electricity forecast in 2015. Similarly, natural gas demand rises from 2.8 quads in 1990 to 3.2 quads in 2015, 0.1 quads less than the Reference Case. Distillate fuel demand falls from 0.5

quads in 1990 to 0.4 quads in 2015, as compared to a steady Reference Case forecast. As in the incremental floorspace scenario, this last trend reflects the declining distillate fuel penetration in new commercial floorspace.

Alternate Fuel Price Scenarios

The fuel price scenarios discussed in this section are generated using price series constructed from the NEMS Restart file. All other default module assumptions as described in the Reference Case forecast are retained in the fuel price scenarios. High and low fuel prices are individually tested and presented, for the major fuels of electricity and natural gas. A high distillate fuel price scenario, holding all other fuel prices at Reference Case levels, is also tested. In order to analyze module performance under dramatic price changes, two extreme cases are analyzed. The first extreme case increases the annual electricity price to 400% of the Reference Case value, for each forecast year. The second extreme case decreases annual electricity prices to 25% of the Reference Case value.

Expected Results

The definition of a normal good states that an increase in the price of a good results in a reduction in the quantity demanded of that good. In addition, the substitution effect postulates that an increase in the relative price of good *x* results in an increase in the demand for goods that are substitutes for good *x*. Assuming that the energy services provided by the fuels under consideration are normal, and recognizing that NEMS Commercial Module permits fuel switching through the Technology Choice submodule, these principles translate into expected changes in demand across all major fuels resulting from alternate fuel price assumptions for individual fuels.

Specifically, the fuel price scenarios performed for this analysis modify individual fuel price projections, holding remaining fuel prices at Reference Case levels. This type of scenario specification alters relative fuel prices, facilitating the analysis of both own-fuel and cross-fuel impacts. The expected results of increasing the price of fuel *f* are a decrease in the quantity demanded of fuel *f* and an increase in the quantity demanded of other major fuels. Analogous to the price increase scenario, price reduction scenarios are expected to result in increases in quantity demanded of the fuel experiencing the price reduction, accompanied by decreases in the quantity demanded of other major fuels whose relative prices rise under the alternate scenario. Minor fuel consumption forecasts are expected to remain at Reference Case levels, since fuel substitution is permitted only across the major fuels that compete to meet service demands within the Technology Choice submodule as described in the Module Documentation Report.

Electricity Price Scenarios

The four alternate electricity price scenarios performed for this analysis are: 110% Reference Case, 90% Reference Case, 400% Reference Case, and 25% Reference Case. Each of these scenario specifications tests a different aspect of module performance. The first two scenarios test a normal range of module sensitivity, and the latter two scenarios test module response under extreme circumstances.

Forecasted energy prices for the 110% Reference Case scenario are provided in Table 3 along with the forecasted consumption for each price scenario. As expected, projected electricity demand rises at an average annual growth rate of 0.6% over the forecast period, as compared to 0.7% in the Reference Case. In addition, natural gas demand rises from 2.8 quads to 3.3 quads over the forecast period, for an increase of 0.1 quads over the Reference Case projection. Projected distillate fuel consumption remains steady under this scenario, reflecting the trend away from the installation of distillate-fired equipment in new commercial floorspace. These trends are also reflected in the fuel proportions of service demand that support this scenario.

Energy price projections for the 90% Reference Case scenario and the corresponding energy demand forecasts by fuel type for this scenario are also found in Table 3. The reduction in Table 3 forecasted electricity prices results in the expected increase in projected electricity consumption over the Reference Case forecast. The increase is slight (only 0.01 quads by 2015) over the

Table 4. NEMS Forecast: Alternative Electricity Prices

Energy Prices (1990 $/MMBtu)						
Electricity	1990	1995	2000	2005	2010	2015
25% of Baseline	6.26	6.04	5.87	5.96	6.17	6.60
90% of Baseline	22.52	21.75	21.12	21.44	22.19	23.77
Baseline	25.02	24.17	23.47	23.82	24.66	26.41
110% of Baseline	27.52	26.59	25.85	26.20	27.13	29.05
400% of Baseline	100.10	96.68	93.88	95.28	98.60	105.64
Natural Gas						
Baseline	4.95	5.08	5.35	5.75	6.36	6.72
Distillate Fuel						
Baseline	4.97	5.00	4.98	5.35	5.44	5.81
Consumption (quads/year)						
Electricity						
25% of Baseline	2.86	3.33	3.72	3.93	4.05	4.10
90% of Baseline	2.86	3.14	3.38	3.45	3.43	3.33
Baseline	2.86	3.13	3.37	3.43	3.41	3.32
110% of Baseline	2.86	3.13	3.36	3.42	3.40	3.30
400% of Baseline	2.86	3.05	3.24	3.26	3.21	3.10
Natural Gas						
25% of Baseline	2.76	2.75	2.69	2.61	2.54	2.46
90% of Baseline	2.76	2.94	3.04	3.11	3.17	3.23
Baseline	2.76	2.95	3.05	3.13	3.19	3.25
110% of Baseline	2.76	2.96	3.07	3.15	3.22	3.29
400% of Baseline	2.76	3.11	3.35	3.53	3.70	3.88
Distillate Fuel						
25% of Baseline	0.49	0.44	0.40	0.37	0.35	0.33
90% of Baseline	0.49	0.48	0.47	0.46	0.47	0.49
Baseline	0.49	0.48	0.47	0.46	0.47	0.49
110% of Baseline	0.49	0.48	0.47	0.46	0.47	0.49
400% of Baseline	0.49	0.45	0.42	0.40	0.39	0.37

Reference Case. Similarly, the corresponding comparison between forecasted natural gas consumption in 2015 for the alternate case and the Reference Case is also slight (a difference of 0.02 quads). Distillate fuel consumption remains steady under this scenario.

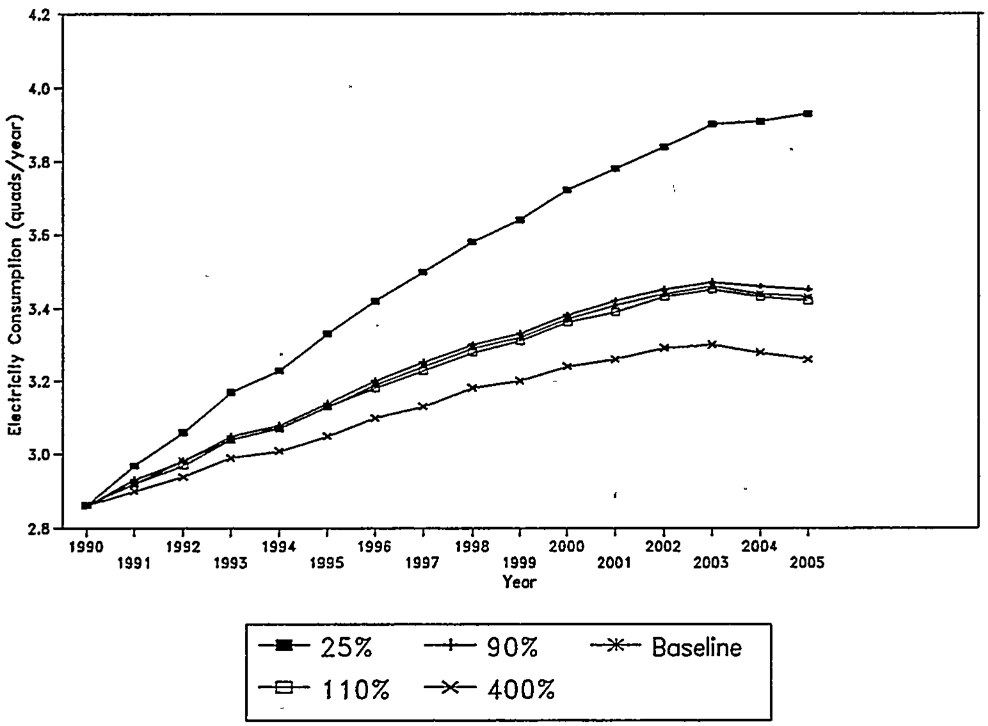

Figure 7. NEMS Forecast under Alternative Electricity Price Assumptions

The 400% Reference Case and 25% Reference Case scenarios test the responsiveness of the module under more dramatic price assumptions. As expected, the extremely high electricity price dampens the upward trend of electricity consumption growth, resulting in an average annual growth rate of 0.3% as compared to 0.6% in the Reference Case. The natural gas consumption forecast increases significantly over Reference Case levels under this scenario, growing at an average annual rate of 1.4%, compared to 0.7% under Reference Case assumptions. Distillate fuel consumption falls at an annual average rate of 1.1% over the forecast period, reflecting the continued steady penetration of natural gas equipment under the 400% scenario. The forecast trends observed in the 400% Reference Case scenario are reversed under the 25% Reference Case scenario, with projected electricity consumption growing at an annual average rate of 1.4% over the forecast period (compared to 0.6% under Reference Case assumptions), and natural gas consumption declining at an average annual rate of 0.5%. Distillate fuel consumption declines even more steeply (1.6% average annual decline from 1990 to 2015), again reflecting market trends away from distillate equipment and relative price disadvantages compared to the other major fuels.

Figures 7 and 8 provide a graphical comparison of the alternative electricity price scenarios and the effect on the levels of consumption in electricity and natural gas, the substitute energy source.

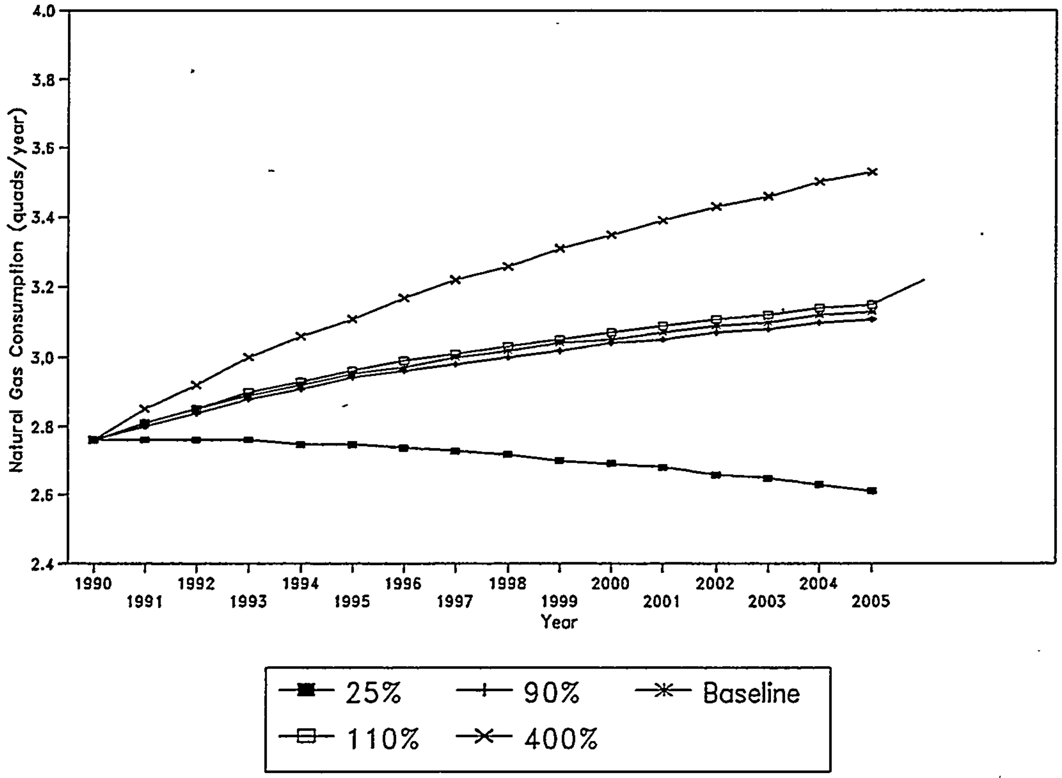

Figure 8. NEMS Commercial Natural Gas Forecast under Alternative Electricity Prices

Natural Gas Price Scenarios

Two alternate natural gas price scenarios are presented in this report: 110% Reference Case and 90% Reference Case. Similar to the electricity price scenarios, these two cases are designed to evaluate module responsiveness in projecting energy consumption and fuel proportions of service demand under alternate price forecast assumptions. As in the electricity price scenarios, all other major fuel prices are held at Reference Case levels while natural gas prices vary, in order to analyze own-price and cross-price impacts.

The fuel prices used in the 110% Reference Case and the energy consumption forecast corresponding to these price series appear in Appendix C to this Module Developer's Report. As expected, the increase in the relative price of natural gas over Reference Case levels results in reduced average annual growth in projected natural gas consumption over the forecast period (0.5% compared to 0.7% in the Reference Case). Projected electricity consumption remains at Reference Case levels, and projected distillate fuel consumption rises at an average annual growth rate of 1.1% over the forecast period, indicating that fuel substitution is occurring from natural gas equipment into distillate equipment, since the relative price of natural gas to distillate becomes higher under this scenario. The corresponding results of the Technology Choice submodule for this scenario support the relative price theory.

Price projections corresponding to the 90% Reference Case appear in Appendix C to this Module Developer's Report, as do the resulting energy consumption forecast by fuel type. As expected, the reduction in natural gas prices compared to Reference Case levels results in increased projected natural gas consumption growth, at an average annual growth rate of 0.8%, compared to 0.7% in the Reference Case. Projected electricity consumption is slightly lower than the Reference Case in 2015 (by 0.01 quads), reflecting the increased relative price advantage of natural gas under this scenario. Similarly, distillate consumption falls from 0.5 quads in 1990 to 0.4 quads in 2015, also reflecting the relative price advantage of natural gas under this scenario.

Figure 9 illustrates the response of the demand for natural gas under the varying price scenarios. Electricity consumption figures are excluded since the graphical presentation does not significantly add to the analysis. This is because electricity consumption is not as sensitive to changes in natural gas prices over the forecast horizon due to the minor effects of cross-price consideration, which are discussed further in the elasticities section of this report. In addition, electricity is the sole energy source for several types of equipment such as lighting, office equipment, etc.

Table 5. Forecasted Energy Demand under Alternative Natural Gas Price Assumptions

Energy Prices (1990 $/MMBtu)					
Natural Gas	1990	1995	2000	2005	2010
90% of Baseline Gas Price	4.46	4.57	4.82	5.18	5.72
Baseline Gas Price	4.95	5.08	5.35	5.75	6.36
110% of Baseline Gas Price	5.45	5.59	5.89	6.33	7.00
Electricity					
Baseline	25.02	24.17	23.47	23.82	24.66
Distillate Fuel					
Baseline	4.97	5.00	4.98	5.35	5.44
Consumption (quads/year)					
Electricity					
90% of Baseline Gas Price	2.86	3.13	3.37	3.43	3.40
Baseline Gas Price	2.86	3.13	3.37	3.43	3.41
110% of Baseline Gas Price	2.86	3.14	3.37	3.44	3.42
Natural Gas					
90% of Baseline Gas Price	2.76	2.97	3.09	3.18	3.27
Baseline Gas Price	2.76	2.95	3.05	3.13	3.19
110% of Baseline Gas Price	2.76	2.91	2.98	3.03	3.06
Distillate Fuel					
90% of Baseline	0.49	0.48	0.47	0.46	0.47
Baseline	0.49	0.48	0.47	0.46	0.47
110% of Baseline	0.49	0.48	0.47	0.46	0.47

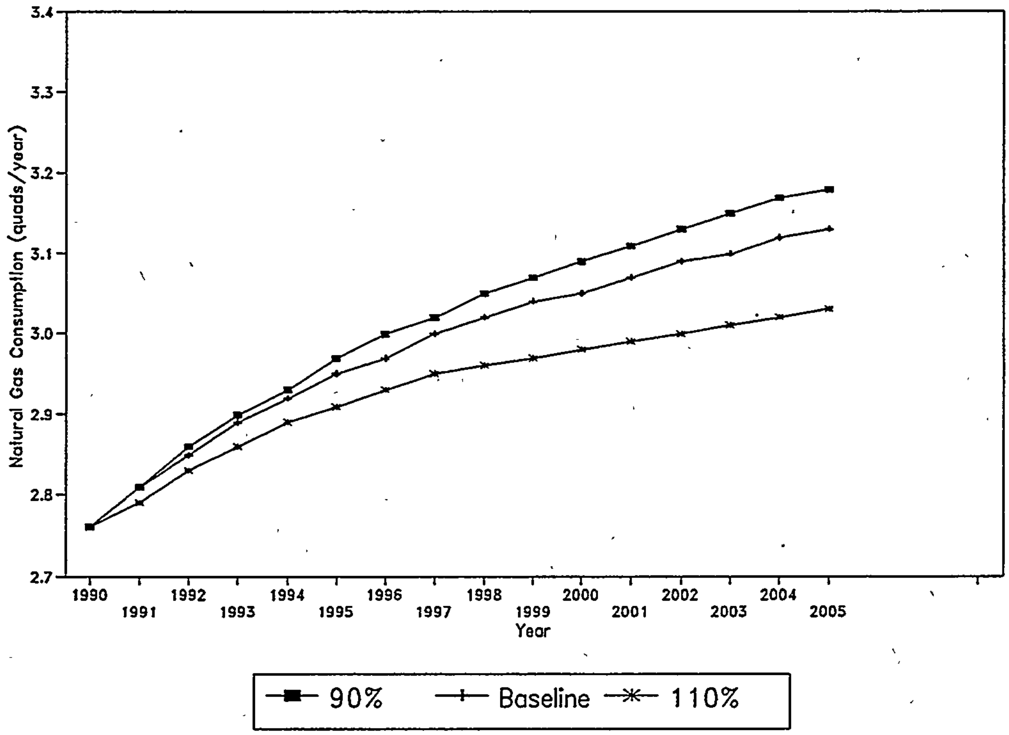

Figure 9. NEMS Forecast of Commercial Sector Natural Gas Demand under Alternative Natural Gas Price Assumptions

Distillate Price Scenario

For completeness in testing module sensitivity under major fuel price assumptions, a 110% Reference Case is presented for distillate fuel. The fuel price series corresponding to this scenario are provided in Appendix C to this Module Developer's Report, including the energy consumption projections resulting from this scenario.

As illustrated in the consumption forecasts, increased distillate prices result in reduced consumption of distillate fuel over the forecast period. Distillate consumption falls from 0.5 quads in 1990 to 0.4 quads in 2015, for an average annual decline of 0.6% over the forecast period, compared to a steady forecast under Reference Case prices. Projected electricity consumption remains at Reference Case levels under this scenario, and projected natural gas consumption rises by 0.7%, compared to 0.6% under Reference Case assumptions. As in the 110% Reference Case scenario for natural gas, this scenario illustrates the fuel substitution that occurs between distillate and natural gas.

Price Elasticity of Demand Calculation

The economic description of the long run is that period in which all inputs vary, including the capital stock. The Technology Choice submodule of NEMS Commercial Buildings Module ensures that capital stock is permitted to vary, since *all* service demand is subjected to the decision-making process, for each year of the forecast period. This effectively ensures that the price elasticity of demand estimates computed by comparing alternate price scenarios of the NEMS Commercial Module are long-run. For purposes of this analysis, long-run price elasticity estimates are computed both within and across fuels, for the three major fuels of electricity, natural gas, and distillate.

The estimated own-price and cross-price demand elasticities are presented in Table 5. As illustrated in the table, the own-price impact for electricity appears small in comparison to the own-price impacts for natural gas and distillate fuel. The primary factor underlying this result is the presence and steady penetration of solely electric end uses such as ventilation systems, office equipment, and refrigeration systems in commercial buildings. In addition, *all* new commercial floorspace utilizes electricity to meet lighting service demand, increasing the complexity of evaluating long-run trends in electricity consumption. In spite of this complication, the own-price elasticity estimates for all three major fuels fall within the range observed in documented analyses.

Cross-price elasticities are not significant for electric and distillate fuel pairs, due to the limited variation across price scenarios. Natural gas consumption displays a symmetric cross-price elasticity with respect to electricity and distillate prices, rising approximately 0.7% for each 1% rise in electricity or distillate price. Distillate displays a comparably large cross-price elasticity of nearly 1.3% for each 1% rise in natural gas price, illustrating fuel substitution behavior.

Table 5. Long-Run Price Elasticity of Demand Estimates

Fuel	Long-Run Price Elasticity of Demand
Electricity	-0.030
Natural Gas	-0.230
Distillate	-0.426

Cross-Price Elasticity of Demand	Electricity	Natural Gas	Distillate
Electricity		n.s.	n.s.
Natural Gas	0.066		0.066
Distillate	n.s.	1.277	

Alternate Behavioral Rule Proportion Scenarios

The assumed proportions of commercial consumers that follow the three behavioral rules are key drivers of the NEMS Commercial Module. The Reference Case assumptions are derived from studies pertaining to consumer characteristics, building characteristics, behavioral patterns, and professional judgement to align the initial proportions as closely as possible with known historical information and expectations. One test of module performance in capital stock decision-making involves assuming that *all* consumers follow a single behavior rule, holding all other module inputs at Reference Case levels. The three analyses that comprise this test are presented in Appendix D of this Module Developer's Report.

All Least Cost Behavior

The Least Cost behavioral rule assumes that commercial consumers consider *all* pieces of equipment that meet a given service, across all fuels, when faced with a capital stock decision. The consumer chooses the piece of equipment that meets the service at the lowest annualized lifetime cost. The "All Least Cost" scenario sets the ratio of consumers following this rule to 1.00, removing all fuel-specific considerations in the decision process. This scenario effectively assumes that decisions are independent of the fuel proportions of the existing equipment stock.

The theory underlying this scenario does not accurately reflect observed market behavior and professional expectations; a certain proportion of consumers are expected to base capital decisions in part on the fuel currently being used to meet that service demand. For example, a commercial consumer that is satisfied with the performance of a natural gas boiler may give greater preference to purchasing another natural gas boiler, as compared to an electric furnace, when the current boiler wears out, possibly due to reasons such as perceived comfort or reliability, that may be independent of relative technology costs.

In this forecast, projected electricity consumption rises at an annual average growth rate of 0.7%, as compared to 0.6% in the Reference Case. Forecasted natural gas consumption rises at only 0.2% on an average annual basis, compared to 0.7% in the Reference Case, and distillate consumption rises at an annual average rate of 0.9%, compared to a steady Reference Case forecast. These trends indicate that, under the Reference Case relative price projections, electric and distillate-fired equipment enjoy cost advantages that are not fully realized when the majority of commercial consumers are assumed to follow the Same Fuel and Same Technology behavioral rules. Fuel proportions of service demand that correspond to this scenario are also provided in Appendix D to this Module Developer's Report.

The module performs as expected under this alternate scenario, given the projected price trends for the major fuels. Under the Reference Case scenario, electricity prices are expected to rise at an annual average rate of 0.2% over the forecast period. Natural gas prices are forecasted to rise 1.2% on an annual average basis, and distillate prices are projected to rise at 0.6% annually. The disparity in price growth rates, along with the reversal of the relative price relationship between natural gas and distillate fuel during the forecast period, drive the results of the Least Cost scenario.

All Same Fuel Behavior

The Same Fuel behavioral rule restricts the capital stock decision to the set of technologies that consume the *same fuel that currently meets the decision-maker's service demand.* The consumer chooses from this subset of available technologies the specific equipment that meets the service at the lowest annualized lifetime cost. The assumption of all Same Fuel behavior effectively eliminates fuel substitution from the Technology Choice submodule.

As in the Least Cost scenario, projected electricity consumption rises at an annual average growth rate of 0.7%, compared to 0.6% in the Reference Case. Forecasted natural gas consumption rises at only 0.2% on an average annual basis, compared to 0.7% in the Reference

Case, and distillate consumption rises at a significantly higher annual average rate of 2.0%, compared to a steady Reference Case forecast.

Two primary conclusions can be drawn from this exclusion of fuel substitution. First, the movement of the commercial market away from electric and distillate space heating and water heating equipment in favor of natural gas equipment is eliminated, resulting in persistence of electric and distillate service demand for these services. This trend contributes to increased growth in the electricity and distillate forecasts at the cost of slower growth in the natural gas forecast compared to the Reference Case. Second, the long lifetimes associated with distillate-fired equipment also contribute to the persistence of distillate market share. These trends are reflected in the service demand fuel proportions presented in Appendix D to this Module Developer's Report.

All Same Technology Behavior

Under the Same Technology rule, commercial consumers consider only the available models of the *same technology and fuel* that currently meets service demand, when facing a capital stock decision. Equipment choices are therefore restricted to the subset of models of equipment available that use the same fuel as existing equipment. For example, a commercial consumer currently using a medium efficiency distillate-fired furnace chooses as its replacement the available distillate furnace model (e.g., medium-efficiency, high efficiency, very high efficiency) that meets the space heating service demand at the lowest annualized cost. The assumption of all Same Technology behavior eliminates both fuel substitution and technology substitution. This is the most restrictive behavioral rule assumption tested in this analysis.

Under the Same Technology assumption, electricity consumption is forecast to be 3.5 quads in 2015, with a forecast annual average growth rate of 0.9%, compared to 0.6% in the Reference Case. Forecasted natural gas consumption rises at 0.1% on an average annual basis, compared to 0.7% in the Reference Case. Distillate fuel consumption falls slightly over the forecast period, at an average annual decline of 0.2%, compared to a steady Reference Case scenario.

Reference Case Forecast

The forecasted increase in electricity consumption compared to the Reference Case (and the Same Fuel scenario) results from the interfuel and intrafuel restrictions imposed under the Same Technology rule. Under the Same Fuel rule, consumers are permitted to choose more efficient technologies using the same fuel currently in place. For example, consumers using inefficient electric resistance space heating equipment are capable of choosing high efficiency electric boilers (that meet the same amount of heating service demand and consume less electricity than resistance equipment) under the Same Fuel rule. In contrast, the Same Technology rule restricts the choice set to the available electric resistance equipment, potentially resulting in a choice that uses more fuel than other electric technologies to meet the same service demand. Projected natural gas consumption trends under this scenario follow the gradual introduction over the forecast period of more efficient natural gas space heating, space cooling, and water heating equipment with competitive capital costs. This trend reflects the movement of the market toward higher efficiency equipment as existing equipment retires, when restricting the choice to the same class of technology.

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Appendix G. Changes to the Model for AEO 95

1. Introduction

Purpose of This Appendix

The purpose of this appendix is to provide updated technical information to supplement the formal Model Documentation Report (MDR) volumes previously prepared for the NEMS Commercial Sector Demand Module[1]. The MDR volumes document the NEMS Commercial Sector Demand Module used to generate the *Annual Energy Outlook 1994* (AEO94). This appendix documents the subsequent enhancements to the NEMS Commercial Sector Demand Module used in the *Annual Energy Outlook 1995* (AEO95) baseline forecast and alternative scenarios.

Organization of This Appendix

As stated in the MDR volumes, the NEMS Commercial Sector Demand Module is composed of five submodules: Commercial Floorspace, Service Demand, Technology Choice, End-Use Consumption, and Benchmarking. The Service Demand, Technology Choice, End-Use Consumption, and Benchmarking submodules have been enhanced in order to provide a more richly detailed commercial sector energy consumption forecast for the AEO95 cycle. As stated in the MDR, the NEMS Commercial Sector Demand Module is a sequentially structured algorithm in the sense that the results generated by one submodule of the code are utilized as input by submodules of the code that execute subsequently. As a result of the changes to the modeling algorithms, many of the module enhancements pursued for the AEO95 cycle span

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1 *Model Documentation Report: Commercial Sector Demand Module of the National Energy Modeling System -- Volume I-Revised Final, February 11, 1994;* Submitted by Decision Analysis Corporation of Virginia, under Contract No. DE-AC01-92EI21946, Task 93054.

Model Documentation Report: Commercial Sector Demand Module of the National Energy Modeling System -- Final Volume II, December 30, 1993. Submitted by Decision Analysis Corporation of Virginia, under Contract No. DE-AC01-92EI21946, Task 93054.

more than one submodule. Therefore, it is not appropriate to categorize the enhancements by submodule.

Instead, the following sections of this appendix are organized by topic heading to describe each of the major areas of enhancement included in the AEO95 version of the NEMS Commercial Sector Demand Module. Each section details the AEO94 methodology, the AEO95 methodology, implementation issues, and supporting data and/or analysis. Table G-1 toward the end of this appendix provides a tabular synopsis of modified and new Commercial Sector Demand Module variables, together with unmodified variables referenced in the equations contained in this appendix. Table G-2 presents definitions of subscripts and constants used in a notational context in the equations in this appendix. Table G-3 provides a tabular summary of changes made to the Commercial Sector Demand Module input files in support of the production of the AEO95.

2. Commercial Sector Lighting Systems

AEO94 Methodology

Analysis of the 1989 Commercial Buildings Energy Consumption Survey (CBECS) yielded the finding that commercial lighting contributed over one quadrillion Btu of end-use electricity, which was approximately one third of total commercial end-use electricity consumption. In order to adequately model this major service, it is necessary to accurately represent the range of available technologies and the corresponding consumer purchasing decisions. The AEO94 version of the NEMS Commercial Demand Module achieved this by competing numerous light bulb selections, including incandescent, fluorescent, compact fluorescent, mercury vapor, sodium vapor, and halogen, based on cost and performance characterizations in the Technology Choice algorithm. Ballast and fixture selections were not explicitly modeled.

AEO95 Methodology

To enhance the treatment of lighting for the AEO95, additional research was conducted to develop commercial lighting *system* characteristics, including lamps, ballasts, and lamp fixtures of numerous sizes and configurations that characterize the current commercial lighting market. Characterization of complete lighting systems in this manner more accurately portrays the purchase decisions faced by commercial sector consumers.

This research effort resulted in the replacement of the light bulb technology data with full lighting systems in the Technology Characterization database. Cost and performance data for incandescent, fluorescent, compact fluorescent, halogen, and High Intensity Discharge (HID) light bulbs, conventional, electronic and magnetic ballasts, and fixtures of numerous sizes and efficacies are now incorporated into the Technology Characterization database. The market choices of these more comprehensively defined lighting systems are now competed in the Technology Choice algorithm of the model, instead of the simpler light bulb competition that was performed for AEO94.

Implementation Issues

The AEO94 design of the Commercial Technology Characterization Database (KTECH) enabled the easy incorporation of all the lighting system characterizations into the model. The Technology Choice algorithm required no additional programming changes to accommodate the lighting system competition, since the algorithm was already designed to model technology competition within all major services. All changes were confined to replacing the light bulb cost and performance data used for AEO94 with entire lighting system cost and performance data used for AEO95 in the Technology Characterization Database (KTECH).

Supporting Data

The data sources that were used to develop lighting system characterizations for the AEO95 version of the Commercial Demand Module are presented below.

- Pietsch, J. *TAG Technical Assessment Guide, Volume 2: Electricity End Use, Part 2: Commercial Electricity Use, 1992 Edition.* Dallas: Electric Power Research Institute, EPRI CU-7222s, Vol.2, Part 2, 1992.

- Sezgen, O., et al. *Lighting Data For Commend 4.0: Draft report of work in progress.* Berkeley: Lawrence Berkeley Laboratory, Energy and Environmental Division, 1992.

- Sezgen, O. et al. *Technology Data Characterizing Lighting in Commercial Buildings: Application to End-Use Forecasting with Commend 4.0, Final Review Draft.* Berkeley: Lawrence Berkeley Laboratory, Energy and Environmental Division, LBL-34243, September 1993.

3. Forecasted Commercial Office Equipment Energy Consumption

AEO94 Methodology

Historical office equipment electricity consumption reported in CBECS 1989 served as the starting point for forecasted office equipment consumption in the AEO94 version of the NEMS Commercial Sector Demand Module. Two exogenously-developed factors were applied to evolve forecasted office equipment: a growth rate in market penetration of office machines and an efficiency trend factor to capture the influx of "green" (energy efficient) computers, facsimile machines and photocopiers in the commercial market. Under the AEO94 Base Case Scenario, office equipment end-use consumption began at 390 trillion Btu in 1990 and rose steadily throughout the forecast to reach 1.01 quadrillion Btu in the year 2010. This significant increase was caused by the dominance of the market penetration rate over the rate of efficiency improvement.

AEO95 Methodology

The office equipment consumption forecast is enhanced for the AEO95 in two ways: first, the market penetration and equipment efficiency factor estimates were updated using published studies referenced in the Supporting Data section below; and second, office equipment is modeled in two distinct categories: a) Personal Computers (PC), and b) Non-PC office equipment. In addition, both the market penetration and equipment efficiency forecast factors are developed for PC and non-PC equipment separately.

These enhancements greatly increase the flexibility with which commercial sector office equipment issues, including DSM programs and federal initiatives targeted toward specific office machinery, can be modeled using the NEMS Commercial Sector Demand Module. For example, the EPA Energy Star Program that focuses on energy-efficiency improvements in PC hardware is easily modeled through the PC-specific market penetration and efficiency growth factors of the AEO95 Commercial Service Demand Module.

Implementation Issues

Implementation of these enhancements required developing input files of the appropriate dimensions, containing data for PC and non-PC applications separately. Corresponding FORTRAN source code was written to process a) PC and b) Non-PC office equipment as two separate services, the results of which are combined to forecast total commercial sector office equipment electricity consumption.

A new user-specifiable parameter, BaseYrPCShrofOffEqEUI, was created and placed in the KPARM input parameter file. If nonnegative, this parameter is used to share out the total office equipment EUI, stored in the Office Equipment:PC position, among PC and nonPC EUI's, as shown in equation 3-1. If the parameter is negative, the PC and nonPC EUI's are retained as input from the KINTENS input file.

Equations 3-2 and 3-3 illustrate the modification of service demand to reflect continued market penetration of Office Equipment:PC, Office Equipment:NonPC, and Other services. These calculations supersede equations 4-9 and 4-10 of the MDR, and equations 4-11 and 4-12 of the MDR have been eliminated.

$$\begin{gathered}\textit{If } BaseYrPCShrofOffEqEUI \geq 0 \textit{ Then}\\ ComEUI_{r,b,s=NonPCOffEq,\,f} = ComEUI_{r,b,s=PCOffEq,\,f} \times (1.0 - BaseYrPCShrofOffEqEUI)\\ ComEUI_{r,b,s=PCOffEq,\,f} = ComEUI_{r,b,s=PCOffEq,\,f} \times BaseYrPCShrofOffEqEUI\\ \forall\ r,b;\ \forall\ f \in \{MajFuels\}\end{gathered} \quad (3\text{-}1)$$

$$\begin{gathered}ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y}\ x\ MarketPenetration_{s,y}\\ \forall\ r,b;\ s \in (OfficeEquipment{:}PC, OfficeEquipment{:}NonPC, Other);\ y\end{gathered} \quad (3\text{-}2)$$

$$NewServDmd_{s,b,r,y} = NewServDmd_{s,b,r,y} \times MarketPenetration_{s,y}$$
$$\forall\ r,b;\ s \in (OfficeEquipment{:}PC, OfficeEquipment{:}NonPC, Other) \qquad (3\text{-}3)$$

Supporting Data

The data sources used to develop forecasted market penetration and energy efficiency improvement factors for a) PC and b) Non-PC office equipment are listed below.

- Policy Research Associates, Inc. *Proceedings: Energy-Efficient Office Technologies. The Outlook and Market.* Electric Power Research Institute. Project 2890-18. December 1992.

- Decision Focus Incorporated. *TAG Technical Assessment Guide. Volume 2: Electricity End Use. Part 2: Commercial Electricity Use--1988.* Electric Power Research Institute. Volume 2, Part 2. Special Report. October 1988.

- H. Dan Nguyen, Rosy Alereza, & Ednan Hamzawi. "Energy Consumption By Computers and Miscellaneous Equipment in Commercial Buildings." California Energy Commission. Undated.

- *Statistical Abstract of the United States, 1990.*

- *Statistical Abstract of the United States, 1991.*

- Brian Johnson. "Energy Star Computers," Environmental Protection Administration. June 22, 1993.

- L. K. Norford, A. Rabb, J. Harris, and J. Roturier "The Sum of Megabytes Equals Gigawatts: Energy Consumption and Efficiency of Office PC's and Related Equipment," CEES and Lawrence Berkeley Laboratory. Undated.

- Mary Jane DeLaHunt. "Trends in Electricity Consumption Due to Computers and Miscellaneous Equipment in Office Buildings." BR Associates, Inc. Undated.

- "The Green Machine," *PC Magazine*. May 25, 1993. pp 110, 112, 120, 122, 124, 126, 135-137, 140-141, and 144-145.

- Arthur D. Little, Inc. *Characterization of Commercial Building Appliances.* Prepared for Building Equipment Division, Office of Building Technologies, U.S. Department of Energy. August 1993.

- Rocky Mountain Institute. *Appliances Volume of E-Source Atlas.* 1990.

- Mark Ledbetter and Loretta A. Smith. *Guide to Energy-Efficient Office Equipment.* Final Report. Prepared by The American Council for an Energy Efficient Economy for the Office of Technology Efficiency Consortium of the Electric Power Institute. July 1993.

4. Forecasted Commercial Refrigeration Energy Consumption

AEO94 Methodology

Historical commercial refrigeration electricity consumption reported in CBECS 1989 served as the starting point for forecasted refrigeration consumption in the AEO94 version of the NEMS Commercial Module. Refrigeration was forecasted as a *minor* service, which means that equipment competition is not performed in the Technology Choice submodule of the Commercial Sector Demand Module. Instead, an exogenously specified efficiency trend factor was applied to the total demand for refrigeration in order to evolve forecasted refrigeration end-use energy.

AEO95 Methodology

The completion of research on refrigeration technologies and specifications enabled the AEO95 version of the NEMS Commercial Module to treat commercial refrigeration as a *major* end use. Full refrigeration systems, including appliances, fans, and motors, are now competed in the Technology Choice algorithm of the Commercial Module. A range of technologies that span the current and proposed future market for refrigeration technologies throughout the commercial sector is incorporated in the model. These include Very Low, Low, and Medium Temperature systems, as well as single unit and multi-unit packaged systems of varying sizes. Numerous door configurations including full glass, strip curtain, and open case models are also incorporated, as well as CFC-based and future non-CFC based systems. Total fuel consumption for refrigeration is calculated based on the efficiencies and market shares of the technology mix selected by the Technology Choice submodule to satisfy the forecasted demand for refrigeration.

Implementation Issues

The original design of the Commercial Technology Characterization Database (KTECH) and related files enabled direct incorporation of refrigeration system characterizations for AEO95. The Technology Choice submodule required further programming to accommodate the additional major service, primarily involving the adjustment of array index upper bounds. Additionally, modifications to the internal report-writing routines were implemented in order to generate detailed refrigeration consumption reports in the KRPT output file.

Supporting Data

The refrigeration technology characterizations are based upon data from the following sources:

- Rocky Mountain Institute. *Appliances Volume of E-Source Atlas*. 1990.

- Decision Focus Incorporated. *TAG Technical Assessment Guide. Volume 2: Electricity End Use. Part 2: Commercial Electricity Use--1988.* Prepared for the Electric Power Research Institute. Volume 2, Part 2. Special Report. October 1988.

- Arthur D. Little, Inc. *Characterization of Commercial Building Appliances.* Prepared for Building Equipment Division, Office of Building Technologies, U.S. Department of Energy. August 1993.

5. District Services

AEO94 Methodology

The AEO94 methodology used in obtaining estimates of district services (space heating, space cooling and water heating) was straightforward. Essentially, estimates from EIA's 1990 Commercial Buildings Energy Consumption Survey (CBECS) of the commercial square footage served by district services were determined and carried throughout the forecast horizon as district service shares. The amount of service demand met through district energy systems in each year was calculated from the district service shares and the forecasted commercial floorspace. The resulting calculated service demand met by district services was then decremented from the total service demand, and the remaining service demand was passed to the Technology Choice submodule to be satisfied by the selection of appropriate competing technologies.

AEO95 Methodology

The 1995 methodology approaches the district services calculation in a completely different manner, which allows a more detailed and dynamic representation of the future growth path of district services. Instead of implementing the prior procedure of determining shares by commercial floorspace, the analysis is refined to obtain district services steam Energy Use Intensity (EUI) estimates by Census Division, building type, and end-use service. The method entails combining the EUI's for the delivered steam energy per square foot, forecasted commercial floorspace, generating fuel shares, and equipment characteristics to forecast district services consumption, as exhibited by equation 5-1. Equation 5-2 is evaluated to provide national totals to the NEMS forecast table output. Equation 5-3 causes end-use consumption to be incremented by fuels used to provide district services for those end-uses, and is evaluated prior to equation 4-63 of the MDR. The accounting of fuels consumed to provide district services is new to AEO95.

Implementation Issues

Implementing the new method in AEO95 proved to be a substantial task. It required setting up new input files for the EUI's for delivered steam energy per square foot, district services efficiency of equipment by fuel, and district services fuel shares which varied by building and fuel. Note that total service demand is no longer decremented by district services because the total service demand is calculated using EUI's from which district service EUI's have been removed. The overall process requires considerably more calculation than the AEO94 version. For a further discussion on the treatment of EUI's, refer to the Energy Use Intensity (EUI) Data and Computations in section 7 of this report.

$$\begin{aligned} DistServConsump_{r,b,s,f,y} = \; & DistServSteamEUI_{r,b,s} \\ & x \; (SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}) \\ & x \left(\frac{DistServFuelShr_{b,f}}{DistServBoilerEff_{f}} \right) \\ & x \; 10^{-3} \end{aligned} \qquad (5\text{-}1)$$

$\forall\, r,b;\ \forall s \in \{DistServ\};\ \forall f \in \{MajFuels\};\ y$

$$CMUSDistServ_{s,f,y} = \left[\sum_{r} \sum_{b} DistServConsump_{r,b,s,f,y} \right] x \; 10^{-3} \qquad (5\text{-}2)$$

$\forall\, s \in \{DistServ\};\ \forall f \in \{MajFuels\};\ y$

$$\begin{aligned} FinalEndUseCon_{f,b,r,y} = \; & FinalEndUseCon_{f,b,r,y} \\ & + \sum_{\forall\, s \in \{DistServ\}} DistServConsump_{r,b,s,f,y} \end{aligned} \qquad (5\text{-}3)$$

$\forall\, b,r;$
$\forall\, f \in \{MajFuels\};\ y$

Supporting Data and Analysis

- Energy Use Intensity (EUI) estimates prepared from CBECS 1989 data by M. Adra and Eugene Burns of EIA. April 1994.

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

- *Assessment of Energy Use in Multibuilding Facilities.* Prepared by U.S. Department of Energy. August 1993. DOE/EIA-0555(93)/1.

- *Commercial Buildings Energy Consumption and Expenditures 1989.* Prepared by U.S. Department of Energy. April 1992. DOE/EIA-0318(89).

- *Commercial Buildings Characteristics.* Prepared by U.S. Department of Energy. June 1991. DOE/EIA-0248(89).

6. Equipment Vintaging

AEO94 Methodology

The AEO94 version of the NEMS Commercial Module incorporated a straightforward assumption that, on average, commercial equipment is retained for 20 years, so that, in a given year, 5% (or, 1/20) of existing equipment in the market retires and is in need of replacement. This split was performed in the Service Demand submodule. The remaining 95% of existing equipment was assumed to be subject to early replacement (retrofit) if economic reasons prevailed from the perspective of a particular consumer behavioral segment, as modeled in the Technology Choice submodule.

AEO95 Methodology

Recognizing that not all equipment survives an average of 20 years, and recognizing that older, less efficient models of equipment are more likely to be replaced in comparison to newer, higher-efficiency models, the AEO95 version of the NEMS Commercial Service Demand Module implements a more sophisticated equipment vintaging algorithm than the AEO94 version of the model.

The AEO95 version of the model utilizes the distribution of equipment lifetimes contained in the Technology Characterization Database (KTECH), and their corresponding market shares of service demand, to develop equipment-specific retirement shares on an annual basis over the forecast period. Specifically, for each service and each different type of equipment in each forecast year, the assumption is made that a proportion of the existing equipment equal to the reciprocal of its lifetime (in years) fails and is in need of replacement. This algorithm recalculates market shares in such a manner as to treat surviving and retiring equipment consistently. Additionally, equipment retirement rates vary across service and through time, consistent with observed market behavior.

Implementation Issues

Implementation of the equipment vintaging design required extensive programming of the FORTRAN source code. This occurred primarily because the equipment retirement proportions and market shares of surviving equipment had to be calculated based on the market shares of service demand and the expected technology lifetime data contained in the Technology Characterization Database (KTECH). The result was a tightening of the coupling between the Service Demand and Technology Choice algorithms of the model.

Equation 6-2 gives the proportion of service demand that is unsatisfied in the current forecast year due to equipment failures, and equation 6-1 gives the absolute amount of such service demand. Equation 6-1 replaces equation 4-19 of the MDR. The adjustment of equipment market shares of service demand to account for the equipment failures is given by equations 6-3 and 6-5, with the corresponding fuel share adjustments given by equations 6-4 and 6-6. These results are new to AEO95, and necessitated revisions to some of the aggregations involving these results. The revised calculations of market shares for new and replacement decision types for the same technology behavior segment are given by equations 6-9 and 6-10, which replace and extend equation 4-27 of the MDR. Equations 6-11 and 6-12 consolidate these results, and replace equations 4-28 and 4-29 of the MDR. For the retrofit decision, market share calculations for all behavior rules were affected, and are given by equations 6-13 through 6-15, which replace 4-33 through 4-35 of the MDR.

$$RetireServDmd_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \times \sum_{\forall t \ni TechbyService(s,t)=1} \frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}} \quad \textbf{(6-1)}$$

$\forall\ s,b,r,y$

$$ReplacementProportion_{r,b,s} = \sum_{\forall\, t,v \,\ni\, TechbyService(s,t)=1} \frac{PrevYrTechShareofService_{r,b,s,t,v}}{TechLife_{t,v}} \qquad \textbf{(6-2)}$$

$\forall\ r,b,s;\ y$

$$SurvivingShareofService_{r,b,s,t,v} = PrevYrTechShareofService_{r,b,s,t,v} \times \frac{\left(1.0 - \dfrac{1.0}{TechLife_{t,v}}\right)}{1.0 - ReplacementProportion_{r,b,s}} \qquad \textbf{(6-3)}$$

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

$$SurvivingFuelShareofService_{r,b,s,f} = \sum_{\forall\, t,v \,\ni\, TechbyService(s,t)=1} [\ SurvivingShareofService_{r,b,s,t,v} \times FuelbyTech(t,f)\ ] \qquad \textbf{(6-4)}$$

$\forall\ r,b,s;\ \forall\ f \in \{MajFuels\}$

$$ReplacementShareofService_{r,b,s,t,v} = \frac{PrevYrTechShareofService_{r,b,s,t,v} \times \left[\dfrac{1.0}{TechLife_{t,v}}\right]}{ReplacementProportion_{r,b,s}} \qquad \textbf{(6-5)}$$

$\forall\ r,b,t,v;\ s \in \{MajServ\}$

$$ReplacementFuelShareofService_{r,b,s,f} = \sum_{\forall t,v \,\ni\, TechbyService(s,t)=1} (ReplacementShareofService_{r,b,s,t,v} \times FuelbyTech_{t,f}) \qquad \textbf{(6-6)}$$

$\forall\ f \in \{MajFuels\};\ s \in \{MajFuels\}$
$\forall r,b;$

$$SFMSN_{t,v} = \sum_{\forall p \ni LCTNRSF_{p,f,1}=t, and LCTNRSF_{p,f,2}=v;\ \forall f \in \{MajFuels\}} [TimePrefProp_{s,p} \times PrevYrFuelShareofService_{r,b,s,f}] \quad \forall\ t,v \tag{6-7}$$

$$SFMSR_{t,v} = \sum_{\forall p \ni LCTNRSF_{p,f,1}=t, and LCTNRSF_{p,f,2}=v;\ \forall f \in \{MajFuels\}} [TimePrefProp_{s,p} \times ReplacementFuelShareofService_{r,b,s,f}] \quad \forall\ t,v \tag{6-8}$$

$$STMSN_{t,v} = \left[\sum_{\forall p \ni LCVNRST_{p,t}=v} TimePrefProp_{s,p}\right] \times \left[\sum_{\forall v'} PrevYrTechShareofService_{r,b,s,t,v'}\right] \quad \forall\ t,v \tag{6-9}$$

$$STMSR_{t,v} = \left[\sum_{\forall p \ni LCVNRST_{p,t}=v} TimePrefProp_{s,p}\right] \times \left[\sum_{\forall v'} ReplacementShareofService_{r,b,s,t,v'}\right] \quad \forall\ t,v \tag{6-10}$$

$$\begin{aligned} MS_{b,s,1,t,v} = {} & BehaviorShare_{s,b,1,1} \times LCMSNR_{t,v} \\ & + BehaviorShare_{s,b,1,2} \times SFMSN_{t,v} \\ & + BehaviorShare_{s,b,1,3} \times STMSN_{t,v} \end{aligned} \quad \forall\ t,v \tag{6-11}$$

$$MS_{b,s,2,t,v} = BehaviorShare_{s,b,2,1} \times LCMSNR_{t,v} + BehaviorShare_{s,b,2,2} \times SFMSR_{t,v} + BehaviorShare_{s,b,2,3} \times STMSR_{t,v} \quad \forall\, t,v \tag{6-12}$$

$$LCMSRet_{t,v} = \sum [TimePrefProp_{s,p} \times SurvivingShareofService_{t',v'}] \quad \forall p;\ \forall\, t',v' \ni LCTRetAF_{p,t',v',1} = t,\ LCTRetAF_{p,t',v',2} = v \quad \forall\, t,v \tag{6-13}$$

$$SFMSRet_{t,v} = \sum [TimePrefProp_{s,p} \times SurvivingShareofService_{t',v'}] \quad \forall p;\ \forall\, t',v' \ni LCTRetSF_{p,t',v',1} = t,\ LCTRetSF_{p,t',v',2} = v \quad \forall\, t,v \tag{6-14}$$

$$STMSRet_{t,v} = SurvivingShareofService_{t,v} \quad \forall\, t,v \tag{6-15}$$

Supporting Data

This enhancement did not require additional supporting data beyond the technology characterization updates documented in Sections 2 and 4 of this report.

7. Energy-Use Intensity (EUI) Data and Computations

AEO94 Methodology

The Energy Use Intensity (EUI) measures energy consumption per square foot for the purpose of providing various end-use services over the period of one year. The EUI values for commercial sector end-use services by Census Division and building type were obtained by EIA personnel through processing of CBECS 89 data. Values for the major services were further processed to yield the fundamental commercial model input measure of Service Demand Intensity (SDI) after additional offline analysis of the 1989 equipment stock market shares and efficiencies. The SDI measures the amount of demand for *delivered* energy per square foot corresponding to the EUI. The amount of demand for a major service that had to be satisfied by the Technology Choice submodule was calculated from these input SDI's, the commercial floorspace forecast, and various other considerations.

AEO95 Methodology

Several significant enhancements were made to the processing and use of EUI's for the AEO95, resulting in a more detailed representation of building energy usage, and greater control over model congruence with external benchmarks having higher resolution than merely Census Division, fuel, and year. At the same time, the need for a separate offline analysis and processing step was eliminated, improving the flexibility and usability from a user standpoint. This was accomplished through several changes to the way EUI's are manipulated. First, the initial processing of CBECS 1989 data was altered to separate out the EUI's attributable to District Services. Additionally, the resulting two sets of EUI's are represented by fuel, as well as the previous dimensions of Census Division and building type. The conversion of EUI's to SDI's has been installed internally in the Commercial Sector Demand Module, by using the base year equipment market shares and efficiencies present in the Technology Characterization Database (KTECH), as shown by equation 7-4. Most significantly, the resolution of the regional base year equipment market shares is greatly enhanced by dispersing shares across building types in such a way as to consider the fuel shares by building type implicit in the input EUI's. This calculation is given by equations 7-2 and 7-3. Note that while the Kscale variable in equation 7-2 exhibits only the dimension of fuel explicitly, it is calculated and applied separately for each Census Division, building type, major service, and forecast year, giving it the corresponding implicit dimensionality. Equation 7-1 shows the calculation of the total energy intensity across fuels, and equation 7-5 illustrates the treatment of minor service energy intensities. Equation 3-1 presents the special considerations given to office equipment prior to application of equation 7-5. Use of the district service EUI's to improve the modeling of district services is described in the section of this report titled, "5. District Services."

Implementation Issues

Extensive reprogramming of the Commercial Sector Demand Module, reprocessing of CBECS 1989 data, and the creation of several new and updated input files were required in order to implement the EUI-related changes for AEO95. The EUI input file structure was modified to support the additional dimension of fuel, and the values now represent EUI's for all services rather than a mixture of major service SDI's and minor service EUI's. District service steam EUI's were derived and placed in a new input file. Initial processing of the Technology Characterization Database was moved from the Technology Choice submodule to the Service Demand submodule to enable the newly-developed internal conversion of EUI's to SDI's. New code was implemented in the Service Demand submodule to distribute the regional market shares of equipment in the base year across building types in such a way as to consider the fuel shares implicit in the input EUI's, as discussed above under the AEO95 Methodology heading.

$$ComEUI_{r,b,s,F} = \sum_{f=1}^{CMnumMajFl} ComEUI_{r,b,s,f} \qquad \textbf{(7-1)}$$

$$\forall\ r,b,s;\ F \equiv \text{"total across fuels"} = CMnumMajFl + 1$$

$$KScale_f = \frac{\dfrac{ComEUI_{r,b,s,f}}{ComEUI_{r,b,s,F}} \times \left[\sum_{\forall t,v \ni FuelbyTech(t,f)=1} \dfrac{TechShareofService1989_{r,b,s,t,v}}{TechEff_{r,s,t,v}} \right]^{-1}}{\sum_{f' \in \{MajFl\}} \left[\left(\sum_{\forall t,v \ni FuelbyTech(t,f')=1} TechShareofService1989_{r,b,s,t,v} \right) \times \dfrac{ComEUI_{r,b,s,f'}}{ComEUI_{r,b,s,F}} \times \sum_{\forall t,v \ni FuelbyTech(t,f')=1} \left(\dfrac{TechShareofService1989_{r,b,s,t,v}}{TechEff_{r,f,t,v}} \right) \right]} \qquad (7\text{-}2)$$

$$TechShareofService1989_{r,b,s,t,v} = TechShareofService1989_{r,b,s,t,v} \times KScale_f$$
$$\forall\ t,v \ni TechbyFuel(t,f) = 1 \qquad (7\text{-}3)$$
$$\forall\ r,b,s; \quad \forall\ f \in \{MajFuels\}$$

$$ServDmdInten1989_{s,b,r} = \frac{ComEUI_{r,b,s,F}}{\sum_{\forall t,v \ni TechEff_{r,s,t,v} \neq 0} \dfrac{TechShareofService1989_{r,b,s,t,v}}{TechEff_{r,s,t,v}}} \qquad (7\text{-}4)$$
$$\forall\ r,b; \quad \forall s \in \{MajServ\}\ ;\ F \equiv \text{"total across fuels"} = CMnumMajFl + 1$$

$$ServDmdInten1989_{s,b,r} = ComEUI_{r,b,s,F} \qquad (7\text{-}5)$$
$$\forall\ r,b; \quad \forall\ s \in \{MinServ\};\ F \equiv \text{"total across fuels"} = CMnumMajFl + 1$$

Supporting Data and Analysis

- Energy Use Intensity (EUI) estimates prepared from CBECS 1989 data by M. Adra and Eugene Burns of EIA. April 1994.

- *Minimal Adjustment of Base Year Equipment Market Shares of Service Demand to Honor Specified Base Year Fuel Shares of Consumption.* Unpublished Technical Memorandum prepared by Decision Analysis Corporation of Virginia for U.S. Department of Energy. April, 1994.

8. Benchmarking to Historical Data

AEO94 Methodology

The AEO94 version of the NEMS Commercial Module was benchmarked to 1990 State Energy Data System (SEDS) values for the commercial sector, by fuel and Census Division, for major and minor fuels. The difference between the 1990 model value and the 1990 SEDS value was multiplied by a user-specified fuel-specific growth rate in order to compute the annual benchmarking value in each subsequent year of the forecast.

AEO95 Methodology

The benchmarking algorithm for the AEO95 version of the NEMS Commercial Module has been substantially enhanced since the AEO94 release of the model. The algorithm provides the capability to benchmark to multiple years, and multiple forecast sources. The model is currently set to benchmark additively to SEDS 1990, SEDS 1991, and SEDS 1992.

The model also contains code to benchmark to EIA's Short Term Energy Outlook (STEO). Prior to benchmarking, the SEDS and STEO data are modified to account for energy use classified as commercial consumption in SEDS and STEO, but which is attributable to other sectors under the NEMS classification scheme. The modification amounts to small decrements to the SEDS and STEO data. The model is currently set to benchmark additively for 1993 and 1994, and then to apply a weather adjustment to the 1994 benchmarking terms which are subsequently applied additively to the remaining forecast years. The weather adjustment accounts for the unusually cold winter of 1993/1994, and amounts to 10 billion cubic feet (BCF) of natural gas at the national level. Because there was insufficient data to permit a determination of the actual distribution of this national total across the Census Divisions, the excess was assumed to be distributed uniformly, yielding 10.236 trillion Btu's per Census Division. This abnormal consumption of natural gas is removed from the benchmarking correction prior to benchmarking beyond 1994, as shown in equation 8-3.

Implementation Issues

The enhanced treatment of benchmarking required both programming changes and the creation of new input files. STEO data for 1993 through 1995 are read from a file and placed in the CMSEDS benchmarking array, which required enlargement for this purpose. The amounts of consumption by which to modify the SEDS data are processed from separate files. The weather adjustment is an additional calculation that also required incorporation into the source code.

Equations 8-1 through 8-3 illustrate the revised calculation of the benchmarking correction, and replace equation 4-64 of the MDR. Equation 8-4 applies the calculated correction, and replaces equation 4-65 of the MDR. For the AEO95 forecast, the value of the KSTEOYR parameter was 6, corresponding to STEO data availability through 1995; however, 1994 was the final year considered for the benchmarking correction calculation.

$$CMNonBldgUse_{f,r,y} = (CMSEDS_{f,r,y} - TranFromSEDS_{f,r,y} - NUGFromSEDS_{f,r,y}) - CMFinalEndUse_{f,r,y} \tag{8-1}$$

$$\forall f \notin (RenewFuels);\ \forall r;\ y < KSTEOYR$$

$$CMNonBldgUse_{f,r,y} = CMNonBldgUse_{f,r,KSTEOYR-1} \tag{8-2}$$

$$\forall f \notin (RenewFuels);\ \forall r;\ y \geq KSTEOYR$$

$$CMNonBldgUse_{NatGas,r,y} = CMNonBldgUse_{NatGas,r,y} - 10.236\ TBtu \tag{8-3}$$

$$\forall\ r;\ y \geq KSTEOYR$$

$$CMFinalEndUse_{f,r,y} = CMFinalEndUse_{f,r,y} + CMNonBldgUse_{f,r,y} \qquad \forall f \notin \{RenewFuels\};\ \forall r,\ y \tag{8-4}$$

Supporting Data

The foundation of the benchmarking algorithm was proposed by EIA's Office of Integrated Analysis and Forecasting, Energy Demand Analysis Branch Benchmarking Team. No additional data were required for this enhancement beyond the STEO forecast and the 1994 weather correction value developed from the STEO forecast.

9. Minor Fuel Consumption Forecasting

AEO94 Methodology

For the AEO94, residual oil, liquified petroleum gas, steam coal, motor gasoline and kerosene are categorized as minor fuels. In determining the forecasts the fuels were first benchmarked to the 1990 State Energy Data System (SEDS) commercial sector consumption data. The forecast was then achieved by applying fuel-specific growth rates to the previous year's consumption for each year of the forecast period. The growth rates used represented average historical rates of growth of minor fuel consumption from 1985-1990 based on published SEDS data.

AEO95 Methodology

For the AEO95, the methodology was improved by refining the analysis of historical minor fuel consumption and pricing. The refinement was achieved by using regression methods to estimate the correlation of minor fuel consumption per square foot of commercial floorspace with respect to the corresponding minor fuel price in constant dollars, over the 23 year period from 1970 to 1992. 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 AEO95 forecast of minor fuel consumption. The entire calculation is given by equation 9-1. Due to insignificant regression results, however, motor gasoline consumption is forecasted using the previous AEO94 methodology, with the exception that benchmarking is performed using SEDS and STEO data through 1995 before applying the growth rate. These considerations are shown in equations 9-2 through 9-4. Equations 9-1 through 9-4 supersede equations 4-56 and 4-57 of the MDR.

Implementation Issues

A new input file containing the minor fuel regression parameters (elasticities) was created for AEO95. Processing the file and using the regression parameters to forecast minor fuel consumption necessitated coding changes to the Consumption submodule of the Commercial

Sector Demand module.

$$FinalEndUseCon_{f,b,r,y} = (e^{MinFuelAlpha_{r,f-CMnumMajFl}}) \times Price_{f,r,y}^{MinFuelBeta_{r,f-CMnumMajFl}} \times 10^{-6} \times (SurvFloorTotal_{r,b,y} + CMNewFloorSpace_{r,b,y}) \tag{9-1}$$

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

$$FinalEndUseCon_{f,b,r,y} = \frac{CMSEDS_{f,r,y} - TranFromSEDS_{f,y,r} - NUGFromSEDS_{f,y,r}}{CMnumBldg} \tag{9-2}$$

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

$$FinalEndUseCon_{f,b,r,y} = \frac{CMSEDS_{f,r,y}}{CMnumBldg} \tag{9-3}$$

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

$$FinalEndUseCon_{f,b,r,y} = FinalEndUseCon_{f,b,r,y-1} \times (1.0 + MinFuelBeta_{r,f-CMnumMajFl}) \tag{9-4}$$

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

Supporting Data and Analysis

- 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 Report 1991, DOE/EIA-0376(91), Washington DC, May 1992.

10. Other Commercial Sector Issues

In order to accommodate individual requests received from the NEMS community throughout the current task performance period, numerous model enhancements were incorporated for the AEO95 version of the model. Several of the modifications requiring changes to the code or associated files are described below.

Execution Time Reduction

Throughout the AEO95 cycle, execution time reductions for the mainframe NEMS runs were pursued. The Commercial Model Team attained a team goal by reducing execution time of the Commercial Model from an average of 7 seconds per iteration to an average of 5 seconds per iteration, for a reduction of 29% in execution time for Commercial in stand-alone mode. This was accomplished primarily through a rederivation of the consumer time preferences from the 11 used for AEO94 to a coarser six used for AEO95. This necessitated rebuilding the time preferences input file, and modifying the parameter that specifies the number of categories. A side effect of this change was a reduction in execution memory requirements, as numerous arrays contain time preference as one of the dimensions.

Nonutility Generation of Electricity

The AEO94 forecast of cogenerated electricity depended on several parameters derived from the AEO93 forecasted electricity prices, necessitating a correction to account for deviation of the AEO94 electricity price forecast from that of AEO93. This linkage was removed for the AEO95 cycle by incorporating a new expression for cogenerated electricity elasticity involving only the prices of cogenerating fuels and electricity for the current and previous forecast years, as shown in equations 10-1, which replaces equations 4-58 and 4-59 of the MDR.

$$CMCogenEl'_{r,b,f,y} = CMCogenEl_{r,b,f,y-1} \times \left[\frac{\left(\dfrac{Price_{f,r,y}}{Price_{elec,r,y}} \right)}{\left(\dfrac{Price_{f,r,y-1}}{Price_{elec,r,y-1}} \right)} \right]^{CMCogenCrossPriceElast_f} \quad \textbf{(10-1)}$$

$\forall\ f \notin (RenewFuels);\ y > 1991;\ \forall\ r,b$

Existing Building Shell Efficiency

In order to model the improvement of building shell efficiencies in the aggregate due to higher shell efficiencies in new commercial floorspace and retrofitting in existing floorspace during the forecast period, the commercial model team implemented a revised functional form for the affected demands for space heating and space cooling, as shown in equation 10-2. The revision amounts to forecasting a linear increase in shell efficiencies from the 1989 value to 2010 indexed values specified in the KSHEFF input file by building type and Census Division, and represents a modification to equation 4-5 of the MDR.

$$ServDmdExBldg_{s,b,r,y} = ServDmdExBldg_{s,b,r,y} \times \left[1.0 - \left(1.0 - \frac{ShellEffIndex_{b,r,1}}{21} \right) \times y \right] \quad \textbf{(10-2)}$$

$\forall\ b,r;\ s \in (SpHeat,SpCool);\ y = CURIYR \equiv calendar\ year - 1989$

Additional Dimensionality of Consumer Behavioral Rules and Time Preferences

In order to support strategic policy analyses of national importance, such as the Climate Change Action Plan (CCAP), the Commercial Model Team proceeded to implement a new level of flexibility into the Commercial Model. The variation of consumer purchasing behavior characterization by Census Division and Building Type used during the AEO94 cycle was, and is, sufficient for the generation of a baseline forecast of energy consumption. The same is true of the consumer time preference premiums, which characterize consumers' perceived time value of money. However, in order to accurately model the effects of policy initiatives which target end-use services to different degrees, the Commercial Model was enhanced to incorporate the additional dimension of end-use service in all calculations involving these consumer characterizations. Additionally, the Commercial Sector Demand Module was modified to allow variation of the consumer time preference premiums with time, in order to model, for example, the reduction to the perceived risk premium resulting from the implementation of a future policy initiative. All equations involving consumer time preferences or behavior rules are affected by the addition of subscripts representing the new dimensions, as shown, for example, in equations 6-9 through 6-12 of this report.

Minor Service Average Efficiencies

Indexed average efficiencies by fuel and year for the three remaining minor services of Office Equipment:PC, Office Equipment:NonPC, and Other, are now calculated and reported in the NEMS Forecast Tables. As efficiency values for these services are represented by values normalized to the 1989 average stock value, so that the 1989 value is one in each case, the result required evaluation as shown in equations 10-3 and 10-4.

$$CMUSConsump_{s,f,y} = [\sum_{r}\sum_{b} EndUseConsump_{f,s,b,r,y}] \times 10^{-3} \qquad \textbf{(10-3)}$$

$$\forall s;\ \forall f \in \{MajFuels\};\ y$$

$$CMUSAvgEff_{s,f,y} = \frac{\sum_r \sum_b [FuelShareofService_{r,b,s,f} \times TSD_{r,b,s,y}]}{CMUSConsump_{s,f,y} \times 10^3} \qquad \textbf{(10-4)}$$

$\forall s \in \{MinServ\},\ f \in \{MajFuel\};\ y$

Table G-1.NEMS Commercial Module Inputs and Outputs

Equation Number in Main Text, This Document	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units	Changed for AEO95
5-1	Floorspace	CMNewFloorSpace	New commercial floorspace by Census Division, building type, and year	Calculated variable	million sq ft	
5-1	Floorspace	SurvFloorTotal	Total surviving commercial floorspace by Census Division, building type, and year	Calculated variable	million sq ft	
3-1	Service Demand	BaseYrShrofOffEqEUI	if nonnegative, proportion of total office equipment EUI attributable to PC Office Equipment	Input Parameter (KPARM)	unitless	x
3-1	Service Demand	ComEUI	1989 Energy Use Intensities (EUI), by region,building,service, and fuel	Input (KINTENS)	thousand Btu in / sq ft	x
5-1	Service Demand	DistServBoilerEff	Efficiency of conversion of fuel f to steam energy by boilers used to provide district services, by fuel type	Input (KDSEFF)	Btu out / Btu in	x
5-1	Service Demand	DistServFuelShr	proportions of district service steam energy generated by each fuel type, by fuel type and building	Input (KDSFS)	unitless	x
5-1	Service Demand	DistServSteamEUI	steam energy per square foot generated to provide District Services by region, building, and service for the three services: Space Cooling, Space Heating, Water Heating	Input (KDSSTM)	thousand Btu out / sq ft	x
7-2	Service Demand	KScale	factor by which to scale regional equipment market shares in buildings to honor EUI fuel shares, by fuel, region, building, and service	Calculated	unitless	x
3-2	Service Demand	MarketPenetration	Market penetration index by service and year for the three services: Office Equipment:PC, Office Equipment:NonPC, and Other End-Uses	Input (KOFFPEN)	unitless	x
3-3	Service Demand	NewServDmd	Service demand in new commercial floorspace, by Census Division, building type, major service and year	Calculated variable	trillion Btu out (not lighting), billion lumen years out (lighting)	
6-7	Service Demand	PrevYrFuelShrServ	Previous year's fuel proportion of service demand by Census Division, building, service and fuel	Calculated variable	unitless	
9-1	Service Demand	Price	Fuel price received from NEMS system, by Census Division, fuel and year	Received from NEMS Syste	constant dollars per million Btu	
6-2	Service Demand	ReplacementProportion	Proportion of existing service demand unsatisfied due to failed equipment, by Census Division, building type, major service, and year	Calculated	unitless	x
6-1	Service Demand	RetireServDmd	Service demand in retiring floorspace by Census Division, building type, service and year	Calculated variable	thousand Btu out/sq ft (not lighting), lumen years out/sq ft (lighting)	
3-2	Service Demand	ServDmdExBldg	Service demand in existing commercial floorspace, by Census Division, building type, major service, and year	Calculated variable	trillion Btu out (not lighting), billion lumen years out (lighting)	
7-4	Service Demand	ServDmdInten1989	1989 Service Demand Intensities (SDI) by service, building,region	Calculated	thousand Btu out / sq ft (nonlighting) lumen years / sq ft (lighting)	x
10-2	Service Demand	ShellEffIndex	Building shell efficiency index by Census Division and building type, for surviving floorspace.	Module Input	unitless	
7-2	Service Demand	TechShareofService1989	1989 equipment market shares of service demand, input and subsequently scaled using KScale, by region,building, service, technology, and tech model	Input (KTECH) Recalculated	unitless	x

Table G-1.NEMS Commercial Module Inputs and Outputs (Continued)

Equation Number In Main Text, This Document	Subroutine In NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units	Changed for AEO95
6-11	Technology Choice	BehaviorShare	Share of commercial consumers following each of the three behavior rules, for new, replacement, and retrofit decision types, by building and major service	Input (KBEHAV)	unitless	x
10-4	Technology Choice	CMUSAvgEff	Average equipment efficiency aggregated across all Census Divisions to obtain U.S. averatge, by service, fuel, and year	Calculated variable	delivered Btu/input Btu for non-lighting; lumens/watt for lighting	
10-4	Technology Choice	FuelShrofService	Fuel share of service demand by Census Division, building type service, and fuel	Calculated variable	unitless	
6-4	Technology Choice	FuelbyTech	A logical variable indicating whether a technology uses the fuel upon which the query is performed	Logical variable	unitless	
6-11	Technology Choice	LCMSNR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the least cost behavior rule for new and replacement decisions	Calculated variable	unitless	
6-13	Technology Choice	LCMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the least cost behavior rule for retrofit decisions	Calculated variable	unitless	
6-13	Technology Choice	LCTRetAF	A logical variable that flags the least cost technology for retrofit decisions across all fuels for the least cost behavior rule, within a consumer time preference premium segment	Logical variable	unitless	
6-14	Technology Choice	LCTRetSF	A logical variable that flags the least cost technology for retrofit decisions across all fuels for the same fuel behavior rule, within a consumer time preference premium segment	Logical variable	unitless	
6-11	Technology Choice	MS	Equipment market share aggregation for retrofit decision type, across behavior rules	Calculated variable	unitless	
10-4	Technology Choice	NSD, TSD, RSD, SSD	Abbreviations for New Service Demand, Total Service Demand Retiring Service Demand, and Surviving Service Demand as defined previously	Calculated variables	thousand Btu out/sq ft (not lighting), lumen years out/sq ft (lighting)	
6-1	Technology Choice	PrevYrTechShareofService	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, by Census Division, building, service, technology type, and vintage	Calculated variable	unitless	
6-6	Technology Choice	ReplacementFuelShareofServic	Fuel shares of that portion of service demand requiring replacement due to equipment failure	Calculated	unitless	
6-5	Technology Choice	ReplacementShareofService	Failed equipment shares of that portion of service demand requiring replacement due to equipment failure	Calculated	unitless	x
6-7	Technology Choice	SFMSN	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for the new decision type.	Calculated variable	unitless	
6-8	Technology Choice	SFMSR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for the Replacement decision type.	Calculated variable	unitless	

Table G-1.NEMS Commercial Module Inputs and Outputs (Continued)

Equation Number in Main Text, This Document	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units	Changed for AEO95
6-14	Technology Choice	SFMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same fuel behavior rule for retrofit decisions	Calculated variable	unitless	
6-9	Technology Choice	STMSN	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for the new decision type.	Calculated variable	unitless	
6-10	Technology Choice	STMSR	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for the replacement decision type.	Calculated variable	unitless	
6-15	Technology Choice	STMSRet	Market share of equipment of a specific technology class and technology vintage within a segment of service demand controlled by consumers following the same technology behavior rule for retrofit decisions	Calculated variable	unitless	
6-4	Technology Choice	SurvivingFuelShareofService	Fuel shares of service after adjustment for equipment failure, by Census Division, building type, major service, major fuel, and year	Calculated	unitless	x
6-3	Technology Choice	SurvivingShareofService	Market shares of surviving equipment after adjustment for equipment failure, by Census Division, building type, major service, equipment, and year	Calculated	unitless	x
7-2	Technology Choice	TechEff	Efficiency of equipment by technology type, vintage, and Censu Division	Model Input	unitless	
6-1	Technology Choice	TechLife	Expected economic lifetime by technology class and technology vintage	Module Input	years; unitless where used as exponent	
6-7	Technology Choice	TimePrefPrem	Consumer time preference premium, by premium segment and major service	Input (KPREM)	unitless	
6-7	Technology Choice	TimePrefProp	Proportions of consumers in each time preference premium segment, by major service	Input (KPREM)	unitless	x
	Consumption	CMCogenCrossPriceElast	Cross price elacticity between fuel f and electricity by fuel	Input (KCOGPRM)	unitless	
10-1	Consumption	CMCogenEl	Forecasted commercial sector cogeneration by Census Division building type, and generating fuel	Calculated variable	trillion Btu	
8-4	Consumption	CMFinalEndUse	Final end-use consumption including cogeneration by Census Division, fuel, and year	Calculated variable	trillion Btu	
9-2	Consumption	CMSEDS	State Energy Data System (SEDS) historical consumption by Census Division and fuel for the commercial sector	Module input	trillion Btu	
10-3	Consumption	CMUSConsump	End-Use consumption by service, fuel and year, summed acros Census Division and building type	Calculated variable	quadrillion Btu	
5-2	Consumption	CMUSDistServ	National consumption of fuels to provide district services by service, fuel and year	Calculated variable	quadrillion Btu	
5-1	Consumption	DistServConsump	Consumption of fuels to provide district services, by Census Division, building type, fuel, year, and the three major services: space cooling, space heating, and water heating	Calculated	trillion Btu in	x

Table G-1.NEMS Commercial Module Inputs and Outputs (Continued)

Equation Number in Main Text, This Document	Subroutine in NEMS Commercial Module	Item	Definition and Dimensions	Classification	Units	Changed for AEO95
10-3	Consumption	EndUseConsump	End-use consumption by fuels, by Census Division, building type, service and fuel	Calculated variable	trillion Btu	
5-3	Consumption	FinalEndUseCon	Final end-use consumption by Census Division, building, fuel and year, summed across services, for major fuels and minor fuels	Calculated variable	trillion Btu	
9-1	Consumption	MinFuelAlpha	regression parameter used in the calculation of minor fuel consumption	Input (KMINFL)	ln [(MMBtu/sq ft) / (1987$/MMBtu)]	x
9-1	Consumption	MinFuelBeta	regression parameter used in the calculation of minor fuel consumption	Input (KMINFL)	unitless	x
8-4	Consumption	RenewFuels	Renewable energy source fuels	Module input	unitless	
8-1	Benchmarking	CMNonBldgUse	Nonbuilding consumption by Census Division, fuel, and year	Calculated variable	trillion Btu	
8-1	Benchmarking	NUGfromSEDS	Commercial-rate consumption for nonutility electric generation systems (NUGS) attributable to the Utility Sector and requiring decrementation from commercial sector SEDS data, by Census Division, fuel, and year	Input (KCALNUGS)	trillion Btu in	x
8-1	Benchmarking	TranFromSEDS	Commercial rate consumption of fuel for transportation purpose (eg, AMTRAK), attributable to the transportation sector, requiring decrementation from commercial sector SEDS data, by Census Division, fuel, and year	Input (KCALTRN)	trillion Btu in	x
		CMnumMajServ	Number of major services, currently 7	Module Parameter	unitless	
		CMnumPref	Number of consumer time preference segments, currently 6	Module Parameter	unitless	
		CmnumBldg	Number of building types, currently 11			

Table G-2. NEMS Commercial Sector Demand Module Equation Subscript Notation

Subscript Designation	Description of Dimension Represented by Subscript	Subscript Values	Abbreviations Used for Subscript Values
r	Census Division	New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific, California, United States	NE, MA, ENC, WNC, SA, ESC, WSC, M, PAC, CA, US
b	NEMS Commercial Module building type	Assembly, Education, Food Sales, Food Service, Health Care, Lodging, Large Office, Small Office, Mercantile/Service, Warehouse, Other	Assem, Edu, FoodSales, FoodServ, Health, Lodg, LgOff, SmOff, MercServ, Whouse, Other
s	End-use service	Space Heating, Space Cooling, Hot Water Heating, Ventilation, Cooking, Lighting, Refrigeration, Office Equipment:PCs, Office Equipment:NonPCs, Other	SpHeat, SpCool, HWH, Vent, Cook, Light, Refr, PCOffEq, NonPCOffEq, Other SpHeat through Refr are abbreviated MajServ as a group; PCOffEq through Other are abbreviated MinServ; SpHeat and SpCool are abbreviated DistServ.
f	Fuel	Electricity, Natural Gas, Distillate, Residual, Liquid Petroleum Gas, Steam Coal, Motor Gasoline, Kerosene, Wood, Municipal Solid Waste	EL or Elec, NG or NatGas, DS, RS, LPG, SC, MG or MotorGas, KS, Wood, MSW Note: EL through DS are abbreviated MajFuels as a group; RS through KS are abbreviated MinFuels; Wood and MSW are abbreviated RenewFuels.
t	Technology Class	1 through CMnumTech (currently 45)	
v	Vintage (model) of equipment	1 through CmnumEqVint (currently 7)	
y	Year designation	1990 through 2015, represented by values of 1 through 26	
p	Consumer time preference premium segment	1 through CMnumPref (currently 6)	

Table G-3. Tabular Summary of Commercial Input File Enhancements

Filename	Summary of Enhancements
KPARM	Switch added to turn off KRPT printing. Non-building benchmarking growth rates modified.
KFLSPC	No changes for AEO95.
KVINT	No changes for AEO95 (includes building stock vintages only, not equipment vintaging).
KBLDG	No changes for AEO95.
KDRI	No changes for AEO95.
KTECH	Addition of refrigeration system technologies. Replacement of light bulbs with lighting system technologies. Update of technology characterizations for other major services. Reformat of file to facilitate import into database.
KINTENS	EUI data updated, and dimension of fuel added. Conversion of EUI's to SDI's for major services automated and placed in code. Office equipment EUI split into PC and other.
KSHEFF	No changes for AEO95.
KOFFPEN	Disaggregated to include PC and NonPC office equipment. Updated data included for both PC and NonPC technologies.
KDSSTM	District steam data file created for AEO95 version.
KDSEFF	District service equipment efficiency file created for AEO95 version.
KDSFS	District service generating fuel share file created for AEO95 version.

Table G-3. Tabular Summary of Commercial Input File Enhancements (Continued)

Filename	Summary of Enhancements
KRENEW	No changes for AEO95.
KSDELA	No changes for AEO95.
KBEHAV	Disaggregated by end-use service to facilitate modeling Climate Change Action Plan (CCAP).
KDELEFF	Refrigeration factor removed; refrigeration competes in Technology Choice for AEO95. Office equipment efficiency trends updated and disaggregated into PC and NonPC equipment.
KCAPFAC	Office equipment capacity factors disaggregated into PC and NonPC equipment.
KPREM	Disaggregated by end-use service. Number of categories reduced to six from 11.
KPREM5	Newly created version of KPREM to be activated in forecast year 1995.
KCOGPRC	No changes for AEO95.
KCOGPRM	No changes for AEO95.
KCOG90	No changes for AEO95.
KCOG91	No changes for AEO95.
KEMFAC	No changes for AEO95.
KCALTRN	Transportation sector adjustment to SEDS created for AEO95 version.
KCALNUG	Nonutility Generation adjustment to SEDS created for AEO95 version.
KSTEO	1993-1995 STEO data/forecast created for AEO95 version.
KMINFL	Minor Fuel regression parameters created for AEO95 version.