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DEVELOPMENT OF AN IMPROVED COMMERCIAL SECTOR ENERGY MODEL FOR NATIONAL POLICY ANALYSIS

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MASTER

Abstract

Pacific Northwest Laboratory provided support to the Office of Conservation and Renewable Energy (CE), under the Office of Planning and Assessment, to develop improved energy and environmental analysis tools. Commercial building sector energy models from the past decade were analyzed in order to provoke comment and stimulate discussion between potential model users and developers as to the appropriate structure and capability of a commercial sector energy model supported by CE.

Three specific areas were examined during this review. These areas provide 1) a look at recent suggestions and guidance as to what constitutes a minimal set of requirements and capabilities for a commercial buildings energy model for CE, 2) a review of several existing models in terms of their general structure and how they match up with the requirements listed previously, and 3) an overview of a proposed improved commercial sector energy model.

Summary

Energy and environmental concerns are becoming increasingly important national issues, and renewable and energy-efficiency technologies are expected to play an important role in improving energy security, in increasing energy and economic efficiency, and in ameliorating environmental problems. The Office of Planning and Assessment (OPA) within the Office of Conservation and Renewable Energy (CE) is responsible for coordinating and evaluating the various federal energy conservation initiatives to ensure that resource allocations are consistent with strategic objectives of the U.S. Department of Energy (DOE). As part of this mission, OPA must ensure that sound analytical tools are developed for assessing the role of CE technologies in the nation's energy and environmental future.

This report is intended to support the OPA by providing guidance in its efforts to develop improved energy and environmental analysis tools. The report focuses on energy models for the commercial building sector, which has shown relatively rapid growth in energy consumption over the past decade. The report is intended to provoke comment and stimulate discussion between potential model users and developers as to the appropriate structure and capability of a CE-supported commercial sector energy model. This discussion will be used to develop a consolidated set of recommendations, and subsequently a long-term model development plan, for an improved energy policy analysis tool for the commercial building sector.

The report involves three topical areas. The first area looks at recent suggestions and guidance as to what constitutes a minimal set of requirements and capabilities for a commercial buildings energy model for CE. The second area reviews several existing models in terms of their general structure and how they match up with the requirements listed previously. The third area provides an overview of a proposed improved commercial sector energy model. A number of topics are discussed that are relevant to the development of such a model.

Three key existing commercial sector end use models that may provide a starting point for an improved analysis tool for CE are reviewed. These models are Jerry Jackson's CEDMS,[a] the Electric Power and Research Institute (EPRI) COMMEND model, and the Pacific Northwest Laboratory (PNL) commercial model. We provide some historical perspective of the models and their basic structure. Important differences are then highlighted and an assessment is made of these existing models with respect to the earlier

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(a) Jackson, J. R. 1988 (not publicly available). *CEDMS - PC User's Guide and Reference Manual*. Prepared for New England Power Pool (NEPOOL) by Jerry Jackson and Associates, Chapel Hill, North Carolina.

identified analytical needs. Although none of the models can satisfy a majority of these currently identified needs, for the near term the COMMEND model appears to offer the best framework for OPA to perform some types of broad policy analyses.

After the review of existing models, we then present an overview of the general structure that we propose for an improved commercial sector model to support CE analytical requirements. In general, it is argued that more attention be paid to the role of the engineering-oriented building simulation models in providing a sound technical basis for the modeling system. Given an integrated structure between the engineering-based models and technology accounting models, we then discuss the types of policy questions that could be addressed with such a model. Two of the top priority activities to support this framework are a detailed technology-cost database and the development of a standard set of prototype buildings.

The analytical core of the end use model concerns efficiency and fuel choice. We recommend a discrete choice framework that explicitly identifies various envelope and equipment technologies. We describe some experiments performed with the microsimulation approach used in the CEDMS model. Some preliminary work was devoted to developing simple regression-based descriptive models of the cost-performance tradeoff for a small sample of data. The tentative conclusion is that it is difficult to characterize both efficiency and fuel choice tradeoffs within a simple single equation framework.

A major issue involves how to simply characterize heating, ventilation, and air conditioning (HVAC) systems in commercial buildings. A proposed classification scheme is developed with the help of some recent EPRI-supported work. Information is also reviewed on HVAC systems that has been collected by the Energy Information Administration (EIA) in their various surveys of commercial buildings. The treatment of lighting in a revised commercial model is then considered. It is recommended that lighting be optimized as a separate component within the model, with separate factors to account for interactions with the HVAC system. This approach is now used in the COMMEND model.

The report briefly discusses lighting and other end uses. A key issue with respect to lighting is its interaction with heating and cooling loads. For other end uses—refrigeration, cooking, hot water, and office equipment—we summarize several recent data collection efforts.

The analysis of prototypical or representative buildings is a key element in the development of a technology-based commercial sector modeling framework. Several methods of how to select such buildings are presented. A suggested approach combines elements of cluster analysis within a grid-based classification system. The report also reviews the prototypical buildings that have been used in prior commercial building sector studies and energy modeling efforts.

The report briefly reviews various engineering-based building energy simulation codes and models (e.g., DOE-2[a]). A generic review is first made of the typical framework of these models, with separate submodels for thermal loads, HVAC systems, and primary conversion equipment. A number of simulation codes are briefly summarized, along with principal advantages and disadvantages. Several new and in-progress building simulation models contain built-in economic optimazation features; these models could be exploited in the future to provide the technical core for an enhanced commercial sector energy model.

The projection of commercial floor space is an important element in projecting future growth of commercial energy use. A review is made of various approaches that have been used in the past to support commercial sector models. Since floor space has not been collected as part of the U.S. economic statistics program, the development of credible historical estimates is a key activity. We describe PNL's approach to develop such estimates, combining data from F. W. Dodge,[b] the U.S. Census Bureau, and the EIA.

Finally, we take a brief look at computer hardware and software requirements for supporting an enhanced commercial sector model. On the hardware side, we examine the merits of various computing platforms for model development, use, and transportability: 1) mainframes, 2) engineering work stations, and 3) advanced personal computers (models 386 and 486). We also examine the relative merits of various programming languages and software environments for an improved model.

(a) DOE-2 is an hourly building simulation program. DOE-2 is maintained by Lawrence Berkeley Laboratory, Berkeley, California.

(b) The F. W. Dodge Division is a section of the McGraw-Hill Information System Co., New York, New York.

Acronyms

ADL	Arthur D. Little, Inc.
ASEAM	a simplified energy analysis method
ACEC	American Consulting Engineers Council
CBECS	commercial building energy consuption survey
CE	Office of Conservation and Renewable Energy
CEDMS	Commercial Energy Demand Modeling System
COSEMS	COmmercial Sector Energy Modeling System
COSTAM	COmmercial Sector Technology Accounting Model
DOE	U.S. Department of Energy
DRI	Data Resources, Inc.
EIA	Energy Information Administration
EIU	end-use intensity
ELCAP	End-Use Load and Consumer Assessment Program
EPRI	Electric Power Research Institute
FEDS	Federal Energy Decision Screening
FEMP	Federal Energy Management Program
FY	fiscal year
GNP	gross national product
GRI	Gas Research Institute
HVAC	heating, ventilation, and air conditioning (system)
ISTUM	Industrial Sector Technology Use Model
LBL	Lawrence Berkeley Laboratory
LSTM	lighting technology screening matrix
NBECS	nonresidential building energy consumption survey
NBECSIM	nonresidential building energy consumption simulation
NEPOOL	New England Power Pool
NEMS	National Energy Modeling System
NWPPC	Northwest Power Planning Council
OBT	Office of Building Technologies
OPA	Office of Planning and Assessment
ORNL	Oak Ridge National Laboratory
OTA	Office of Technology Assessment

PC	personal computer
PE	Office of Policy and Evaluation
PNL	Pacific Northwest Laboratory
R&D	research and development
REEPS	Residential End-Use Energy Planning System
SAS	Statistical Analysis Software
TC	Technical Committee
VAV	variable air volume

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1.0 Introduction

Energy and environmental concerns are becoming increasingly important national issues, and renewable and energy-efficiency technologies in all sectors (utility, industrial, transportation, and buildings) are expected to play an important role in improving energy security, in increasing energy and economic efficiency, and in ameliorating environmental problems.

Within the Office of Conservation and Renewable Energy (CE), the Office of Planning and Assessment (OPA) must coordinate and evaluate the programs administered by each of the deputy assistant secretaries to ensure that resource allocations are consistent with strategic objectives and that sound analytical tools are developed for assessing the role of CE technologies in the nation's energy and environmental future. It is important that tools be developed in such a way that they can work together consistently and that cross-cutting issues--those that affect more than one sector--can be analyzed effectively. In addition, OPA must coordinate its efforts with analyses throughout the U.S. Department of Energy (DOE) and with activities outside DOE.

This report is intended to support OPA in its mission by providing guidance in the development of improved energy and environmental analysis tools. The report focuses on the commercial building sector, which in the aggregate, has displayed the highest rate of energy consumption growth of any of the major use sectors during the past decade. The complexity of commercial buildings and the heterogeneity of the building stock have made this sector one of the most difficult to analyze in terms of policy-oriented end-use energy models.

This report also represents part of Pacific Northwest Laboratory's (PNL)[a] support of the National Renewable Energy Laboratory in its lead role to CE in developing, integrating, and coordinating data, modeling, and energy analysis. Because databases and energy models represent a core element in CE's ongoing capability to analyze programs and technologies, thorough assessments and coordination represent essential investments for the program. Our work related to commercial sector modeling falls under the first two of four separate (fiscal year [FY] 1991) task areas for this purpose:

- support to the integrating model framework
- development of buildings model

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

- development of industrial model
- examination of noneconomic factors in energy efficiency.

1.1 Scope

The scope of the report involves three topical areas. The first area looks at recent suggestions and guidance as to what constitutes a minimal set of requirements and capabilities for a (commercial) buildings energy model for CE. The second area reviews several existing models in terms of their general structure and how they match up with the requirements listed previously.

Most of the report focuses on the third area--an overview of a proposed improved commercial sector energy model. A number of topics are discussed that are relevant to developing such a model. Where possible, some alternative approaches are presented to various model elements and a preferred approach is recommended.

This report does not delineate a specific long-term plan for developing such a model. The principal purpose of the report is to elicit dialogue among potential model developers and model users in order to arrive at a general consensus regarding model approach. However, the report prioritizes what are believed to be the most critical areas that should first receive attention.

1.2 Organization of Report

The report consists of twelve sections. Section 2.0 provides the rationale for CE-supported activities related to a commercial sector end-use model. Some of the salient points concerning the role of end-use models that have emerged from the (ongoing) analytical requirements analysis conducted by OPA are summarized.

Section 3.0 reviews three key existing commercial sector end-use models that could provide a starting point for an improved analysis tool for CE. Models reviewed are Jerry Jackson's CEDMS, the Electric Power Research Institute's (EPRI) COMMEND model, and PNL's commercial model. The section provides historical perspective of the models and their basic structure. Important differences are then highlighted and these existing models are assessed with respect to the analytical needs identified in Section 2.0.

Section 4.0 provides an overview of the general structure that we propose for an improved commercial sector model to support CE analytical requirements. We discuss the

types of policy questions that could be addressed with such a model. Finally, some the key areas where new work must be performed to support such a model are prioritized.

The remainder of the report examines various topics that are relevant to developing the enhanced model framework. In many cases, potential approaches to various model elements are presented and a preferred approach is recommended. Because the model is intended to eventually support OPA's integrated model system, some issues must be left open at this point (e.g., regionality or software). Nevertheless, the information and discussion here should help guide the decisions that have to be made at a broader level.

Section 5.0 examines the analytical core of the end-use model--efficiency and fuel choice. A discrete choice framework is recommended that explicitly identifies various envelope and equipment technologies. Some experiments performed with the microsimulation approach used in the CEDMS model are described.

Section 6.0 examines the issue of how to simply characterize heating, ventilation, and air conditioning (HVAC) systems in commercial buildings. A proposed classification scheme is developed with the help of recent EPRI-supported work. Also, the information on HVAC systems that has been collected by the Energy Information Administration's (EIA) various surveys of commercial building is reviewed.

Section 7.0 proposes a general approach for modeling lighting and other end uses in a revised commercial model. A key issue in treating these end uses is their interaction with the HVAC system.

The analysis of prototypical or representative buildings is a key element in developing a technology-based commercial sector modeling framework. Section 8.0 discusses several methods of how to select such buildings and suggests a general approach. The section also reviews the prototypical buildings that have been used in several prior studies and building energy modeling efforts.

Section 9.0 reviews various engineering-based building energy simulation codes and models (e.g., DOE-2). The section begins by reviewing the typical framework of these models, with separate submodels for thermal loads, HVAC systems, and primary conversion equipment. The section then briefly summarizes a number of simulation codes, along with principal advantages and disadvantages.

The projection of commercial floor space is the subject of Section 10.0. The approaches that have been in used in the past to support commercial sector models are reviewed. Because floor space has not been collected as part of the U.S. economic statistics program, developing credible historical estimates is a key activity. The section

describes PNL's approach to develop such estimates. The section concludes by discussing several issues related to floor space projections--regionality and the potential use of projections made by Data Resources, Inc. (DRI).

Section 11.0 briefly examines hardware and software. On the hardware side, the merits of various computing platforms for model development, use, and transportability are examined: 1) mainframes, 2) engineering work stations, and 3) advanced (386, 486) personal computers (PCs). Also examined are the relative merits of various programming languages and software environments for the model.

2.0 CE Analytical Needs and Commercial Model Capabilities

This section examines the analytical needs within CE that are relevant to further development of a commercial sector energy end-use model. First, the ongoing requirements analysis being conducted by the OPA are reviewed. Second, major categories of policy levers are listed that such a model might address. Finally, some general capabilities of building sector models that relate to the requirements analysis are prioritized.

2.1 OPA Requirements Analysis

OPA is currently involved in developing a formal requirements analysis for CE's planning and policy research activities. The goals of this work are two-fold: 1) identify and assign values related to CE-wide planning, evaluation, and analysis; and 2) prioritize activities that will produce the needed information. The requirements analysis is based on a survey of key analysts and program managers, both within DOE and in supporting organizations (national laboratories and other contractors). The discussion below is based on some preliminary results of this work.[a]

2.1.1 Role of CE Planning and Research Decisions

Figure 2.1, adapted from a progress report briefing of the requirements analysis, depicts how CE planning and policy research decisions influence CE goals. The fundamental goals of CE are deemed to be 1) improving U.S. competitiveness in international trade, 2) promoting energy security by reducing oil imports, and 3) contributing to environmental quality. The left side box represents CE decisions concerning planning and policy research, which might include information gathering, modeling building, program planning, and prioritization methods.

The focal point of the figure from OPA's point of view relates to the outcomes of CE planning and policy research. Two objectives are shown: 1) to guide technical research decisions, and 2) to provide input to federal energy policy decisions.

The oval-shaped elements in the figure denote aspects of uncertainty in the process. Therefore, as the figure shows, the outcomes of CE planning and research are recognized to contain uncertainty. The oval on the bottom left of the figure represents uncertainties that impinge on the research outcomes. Such uncertainties may arise from both technical

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(a) The discussion is based on a progress report presentation by Greg Hamm of Applied Decision Analysis, made to CE staff on February 12, 1992.

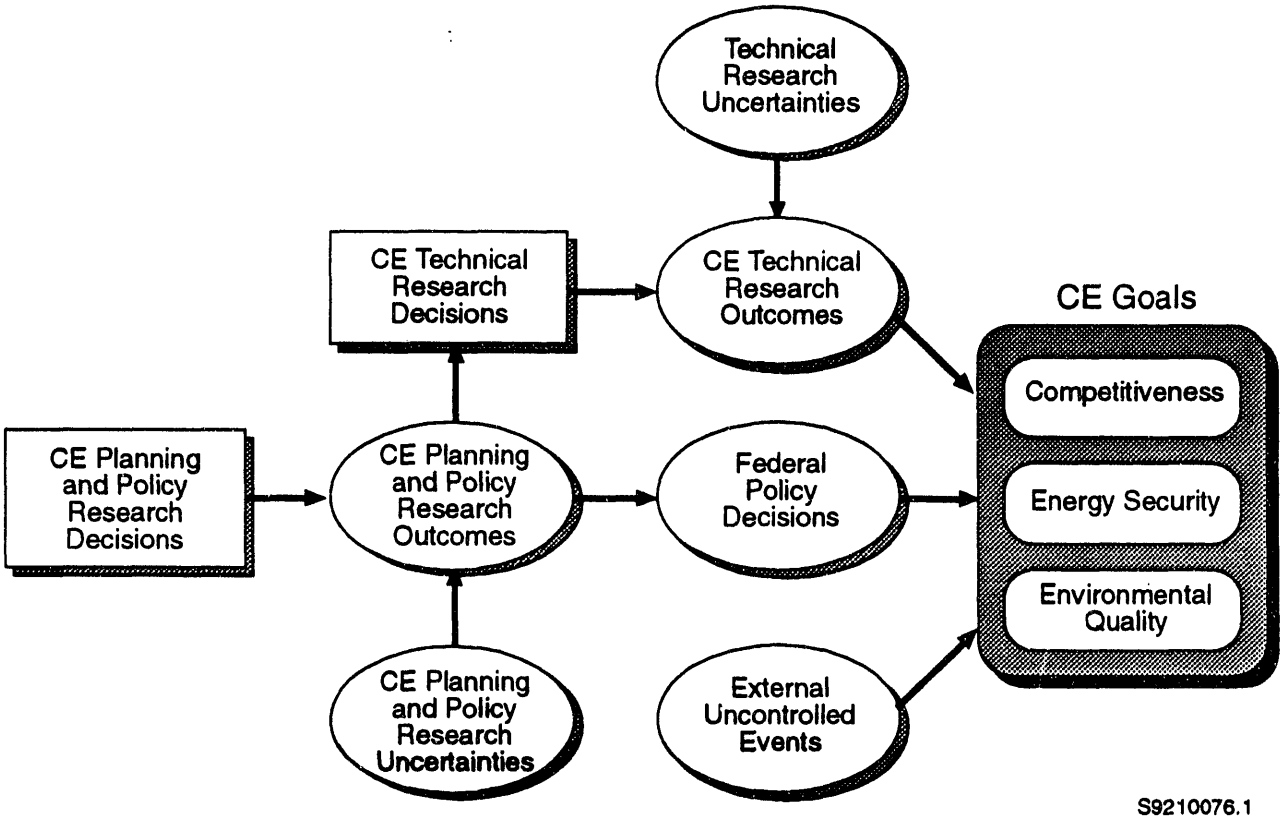

Figure 2.1. Influence of CE Planning and Policy Research Decisions

and programmatic sources. On an analytical basis, this uncertainty may arise, for example, from incomplete understanding of consumer decision behavior. Historical (statistically based) analysis of government policies often do not reveal clear cut answers--prior studies of the federal conservation tax credits are a good example. Programmatically, uncertainty is involved with shifting budget priorities. Long-term and ambitious research agendas carry the risk of being reduced in scope or terminated before substantive conclusions can be reached.

2.1.2 Survey Responses Related to Commercial Sector Modeling

The interviews conducted for the requirements analysis covered a wide range of topics, from the overall responsibility and structure of CE as a whole, to the role of OPA. Although the requirements analysis does not focus on individual sector models, several of the questions are relevant to the direction of the overall modeling effort for the commercial sector.

As stated above, the discussion here is based on only the first round of formal interviews (a first set of "scoping" interviews was also conducted).[a] Thus, conclusions based on this work must be classified as tentative. However, our view is that some of the basic emphases will not be altered even with a larger sample.

Thus far, the respondents indicate that one of the most important activities to improve CE's internal planning process is to improve the general information base. This activity was ranked higher than the development of uniform methods of internal project evaluation. Better information was deemed roughly twice as important as the development of a peer review process or improved energy-economy models.

A related question inquired about the types of information most needed within CE: given the two general influences of CE planning and policy research--internal research and development (R&D) evaluation and input to external policy development--what types of information should be gathered to support each of these responsibilities? Furthermore, respondents were asked to provide some guidance as to the emphasis that CE should place on the various types of information. Respondents were asked to provide hypothetical budget allocations for four types of information:

- CE and competing technologies
- markets for energy technologies
- policy actions and effectiveness
- basic economics.

Two separate budget allocations were solicited, one to support internal evaluation and a second to provide input to external policy development. Several rough quantitative results are indicated from the first round of the interview process (approximately one-half of the ultimate sample). Not surprisingly, the respondents, as a whole, allocated the bulk of the budget (two-thirds) for internal evaluation to the first two information types shown above. However, even for input to external policy development, the respondents indicated that specific technology-based information (again, types 1 and 2 shown above) should receive most of the budget. Even though information on policy actions and effectiveness is judged more important for external policy development than internal evaluation, as a

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(a) The quantitative results are based on 24 closed interviews, somewhat more than half of the total envisioned for the complete study.

whole the respondents felt it should receive only a quarter or less of the total information budget. Information on basic economics was generally viewed to require the least amount of resources.[a]

Finally, one question in the first round of interviews related to various types of models of energy-economy interactions. Respondents were asked to provide some guidance as to the relative importance of various types of these models. Collapsing the various model types into broad groups and converting the numerical scores into qualitative rankings, the general results were as follows:

Consumer choice and market penetration	1
National, regional, and sector-specific with little or no feedback	2
National, regional, and sector-specific energy-economy	3
Simple national or regional all-sector with feedback	4

Although the models in the survey instrument must be better characterized, the preliminary general results are consistent with the responses given for CE information requirements. Models that can deal with consumer choice and market penetration are deemed most important. Presumably, such models could incorporate information about specific CE and competing technologies and their key markets. Next in importance are sector-specific models that may contain little or no economic feedback (e.g., the price impact of a new technology that shifts energy demand). Although not spelled out in the question, such models would likely include, for example, the Lawrence Berkeley Laboratory (LBL) residential model and the EPRI-sponsored models for the buildings sectors (COMMEND and the Residential End-Use Energy Planning System [REEPS], respectively). Ranked lowest in importance from a CE perspective were all-sector models with feedback, as represented by the forthcoming National Energy Modeling System (NEMS), which is under development by EIA, and the system dynamics Fossil-2 model.

2.2 Policy Levers

The OPA requirements analysis is not the only activity that has recently addressed the analytical needs within CE that relate to end-use energy models. As input for a buildings sector analysis workshop in the spring of 1991, Henry Kelley and Jeff Harris developed a list of policy levers they believed that an analysis and modeling tool should be able to

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(a) Based on other responses in the requirements analysis, this result likely reflects the view that other agencies within DOE (EIA and Office of Policy and Evaluation [PE]) are more responsible for this type of information.

evaluate for CE.[a] The list is reproduced below as Table 2.1. Kelley and Harris[b] recognized that for a number of the policy levers listed, development of impact estimates may require some calculations outside the formal analysis tool.

The categories of policy levers listed by Kelley and Harris reflect the wide range of analytical needs throughout CE. The OPA requirements analysis appears to have focused the technical research decisions arena (see top left rectangle in Figure 2.1) on CE-sponsored research for new technologies. Harris and Kelley took a broader view. The presence of the Office of Utility Technology indicates some need to evaluate various utility-related policies. While not directly supporting development of new technologies, Congress has recognized codes and standards as a principal means of accelerating the adoption of energy-efficient technologies. Congress has also recognized the need for the federal government to be aggressive in efforts to save energy in its own facilities.

2.3 General Model Requirements

As part of the same 1991 building sector analysis workshop, Kelley and Harris also developed a set of general capabilities required for buildings sector models. It is a very ambitious set of capabilities; as the next section illustrates, no currently available model satisfies even a majority of items listed. Table 2.2 groups this set of capabilities into three categories, based on our judgments as to how they relate to the results from the broader OPA-sponsored requirements analysis.

The first group shows model capabilities that we deem essential to support technical research decisions in CE (OBT and OPA). Energy savings by fuel type remain the fundamental metric used within CE to evaluate various programs (e.g., the Multi-Year Plan). Cost information for both energy use and capital investment is important to provide a framework to evaluate CE programs relative to other government activities (e.g., costbenefit analysis). The treatment of environmental residuals ties directly to one of three major CE goals, as identified in the requirements analysis (see Figure 2.1).

A proper accounting of the benefits of new CE-sponsored buildings research requires attention to interactions among building technologies. In the past, lack of such attention has lead to "double counting" of savings, leading to loss of credibility for building sector savings estimates. Treatment of interactions will help to provide a more realistic framework to analyze market penetration of specific technologies and programs.

(a) As a senior energy analyst in the Office of Technology Assessment (OTA), Henry Kelley was serving in a special assignment to OPA. Jeff Harris, LBL, is a buildings analyst who was working in CE's Office of Building Technologies (OBT) as a special advisor.

(b) Kelly, H., and J. Harris. "Background Materials for Work Session on Buildings Sectoral Modeling." Fax transmittal to Dave Belzer, PNL, on May 29, 1991.

Table 2.1. Policy Levers for New Analysis Tool[a]

A. Research and Development

— Changes in product and process technology likely to occur in the absence of government interventions: R&D cost sharing, federal investment in basic research, and macroeconomic policy designed to encourage longer planning horizons

— The consequence (measured in short-, intermediate-, and long-term and by region) of meeting specified research objectives (e.g., price, performance, or other features) measured by the following:

- impact on U.S. demand for electricity and fuels
- impact on energy trade
- environmental impacts
- income and employment for domestic industries
- impact on energy services for households, businesses, and the nation as a whole

— The value of information about technology performance and program performance developed from demonstration programs and the value of reducing uncertainty.

B. Utility Programs

— Impact of rate structures (increasing block rates, time of day,demand and energy rates, etc.)

— Utility promotional activities in efficiency (conserving general messages, buying efficient products, operating under and maintaining good practices, etc.)

— Utility-sponsored audits

— Low-interest loans

— Purchase of saved energy (via bidding or other)

— Utility service hook-up requirements or feebates

— Accelerated retirement/replacement of older appliances

— Incentives or requirements for fuel choice (new construction) or fuel switching (existing)

Table 2.1. (contd)

— Electric load shifting or demand control incentives, hook-up requirements, etc.

C. Standards, Labeling, and Related Programs

— Impact of standards implemented on specific technologies and processes

— Impact of standards likely to be undertaken by state and local programs that are already planned

— Impact of labeling a variety of products or otherwise providing information about cost and performance

— Impact of labeling new and existing structures at time of sale

— Impact of energy-efficient mortgaging.

D. Federal, State, and Local Buildings

— Standards for new federal, state, and local government structures or leased structures

— Retrofit requirements for public structures (revolving fund, bond authority, etc.)

— Standards and retrofit requirements for publicly assisted housing.

E. Other Programs

— Tax credits/deductions

— Performance guarantees (manufacturers, distributors, builders, utilities, energy service companies)

— Retrofit-on-resale requirements.

(a) Kelly, H., and J. Harris. "Background Materials for Work Session on Buildings Sectoral Modeling." Fax transmittal to Dave Belzer, PNL, on May 29, 1991.

Table 2.2. General Model Capabilities: Prioritized Categories

High Relative Importance to Requirements Analysis

1. Show energy amounts and costs (including reflection of rate structure, not just average rates) by fuel type, including peak kW demand and demand costs.

2. Calculate net changes in dollar cost (to whom) and dollars of capital investment (by whom) for energy services.

3. Estimate dollars and physical amounts of environmental residuals avoided.

4. Treat interactions among measures (e.g., shell integrity versus system efficiency).

5. Integrate supply curves with efficiency (physical measures and operating practices), solar and other renewables, onsite power, and fuel switching ranked as options.

Medium Relative Importance to Requirements Analysis

6. Document all input values (easy to change but user must sign, date, and explain input).

7. Facilitate display of modeled choices (i.e., on demand can display efficiency trends and fuel mix by year, region, and building type).

8. Disaggregate average (median) values as needed (e.g., efficiency of new appliance categorized by those not meeting standard, just meeting, exceeding, and "best-practice").

9. Estimate value of energy *beyond* average dollars per kWh (i.e., value of avoided peak electricity generating and the transmission and distribution capacity).

10. Focus on decision makers first, then type of building, physical features, and efficiency options.

Low Relative Importance to Requirements Analysis

11. Ensure that the model is directly usable by OPA/OBT staff.

12. More generally, allow for "open architecture" so algorithms and submodels can be added or changed in the future.

13. Validate through backcasting.

The development of a supply curve builds on the availability of technology cost and physical interaction estimates, described above. A supply curve can be traced out by the model by successively changing fuel prices. The resulting curve could then be used as a straightforward mechanism to generate estimates of both technical and economic conservation potential in buildings.

Three of the capabilities in the "medium" category relate to model structure and software. Because OBT-sponsored research will generally impact only portions of the entire commercial sector, it is important to be able to present disaggregated model results. Technology detail, with varying efficiency classes, is implied in number 7 of Table 2.2. It is recognized that equipment standards truncate the distribution of products sold. The model must have some means of characterizing that distribution without standards.

Several capabilities related to software are in the "low" category. While desirable from a long-run point of view, an "open architecture" and highly user-friendly environment are relatively costly to achieve. Staff turnover and budget cycles in the past have generally prevented CE from maintaining in-house capability to operate the various end-use models.

While important from a pure forecasting point of view, historical model validation is not as critical for the long-term policy-directed models needed by CE. The time horizon for the CE models (up to 40 years) is usually much longer than the available data period for current model validation.

3.0 Current Commercial Sector End-Use Models: Background and Assessment

This section provides background information and an assessment of the major existing commercial sector models that could be used by various offices within CE. After a brief history and general overview of some of the key commercial use models, a limited comparison of the major components within the models is discussed. Next, a subjective discussion is presented on how three of these models relate to current CE and OBT policy analysis and program planning needs. The section concludes with general recommendations on which models or model components might provide the best starting point for an enhanced policy tool for CE and OBT.

3.1 Brief History

In the wake of the 1973 oil embargo, with attendant prospects of ever-rising real energy prices, there was an increased need for improved models to evaluate energy conservation policies. To meet this and other related needs, a flurry of activity was devoted to energy analysis and modeling. For the residential and commercial buildings sectors, this activity culminated in the development of disaggregated end-use models at Oak Ridge National Laboratory (ORNL) in the mid-1970s.

The ORNL commercial sector model effort was led by Jerry Jackson. The original 1976 ORNL model provided forecasts of commercial sector energy use by eight end uses, ten building types, and three fuels. Explicit engineering information was incorporated in the model in the form of functions to represent the tradeoff between greater energy efficiency and higher capital cost. A major model development activity involved estimating national floor space stocks by building type and average fuel consumption for specific end uses (Jackson and Johnson 1978). Basic data construction involved considerable judgment and imputation procedures on the part of Jackson and his project team. This work was conducted before the EIA's national survey of commercial buildings and with very limited availability of metered or audit-based estimates of end-use consumption.

Despite data limitations, the promise of the disaggregated end-use approach was rapidly accepted. EIA adopted the model as part of its mid-term energy forecasting framework. CE, the model's principal sponsor, used the model to assess various conservation policy issues.

Figure 3.1 shows the time line and linkages of major commercial sector end-use models. As the figure shows, the major commercial sector end-use models in current use

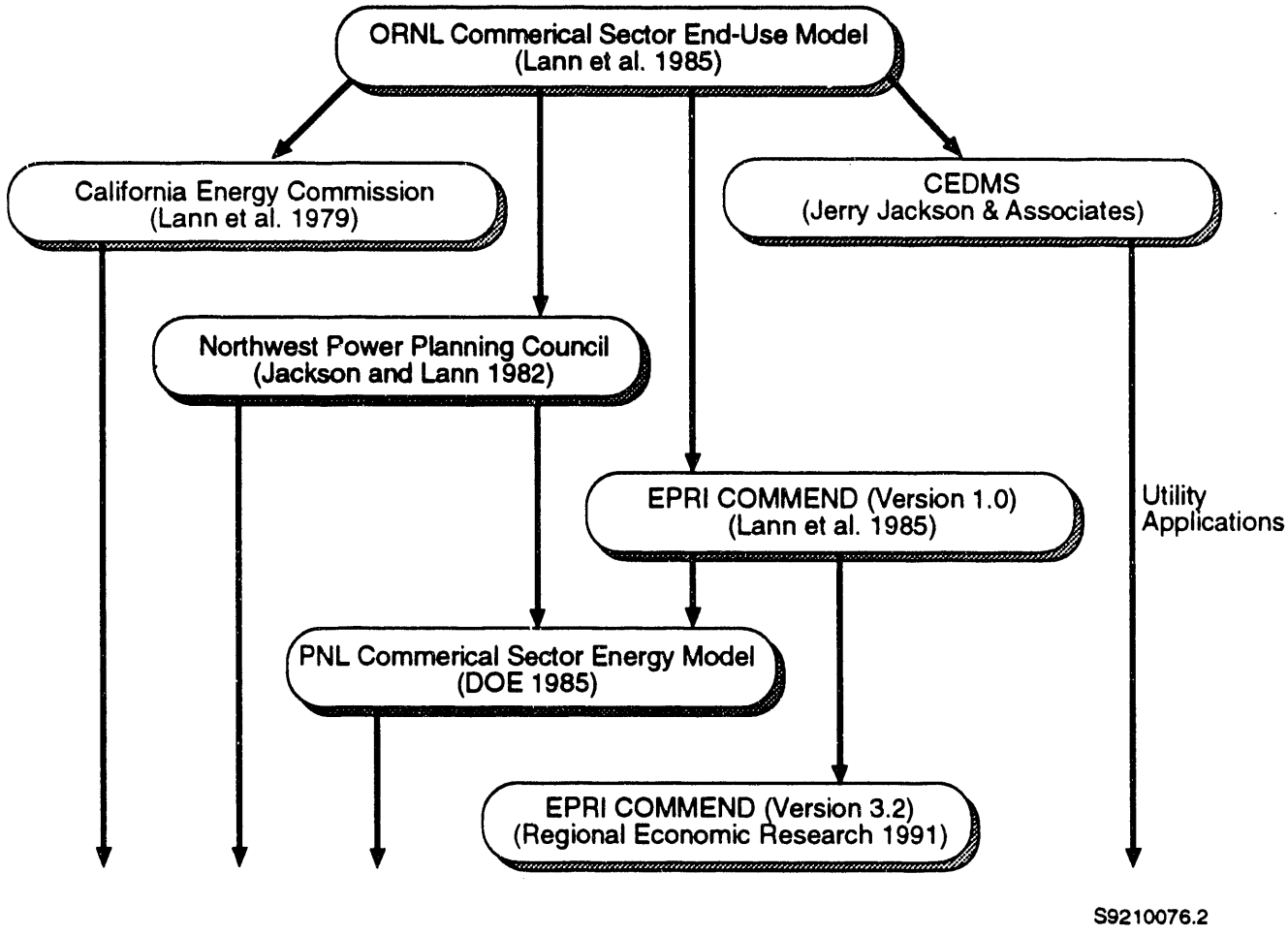

Figure 3.1. Time Line Linkages of Major Commercial Sector End-Use Models

all can trace lineage to the 1976 ORNL specification. The first adaptation of the model at the subnational or utility service area was by the California Energy Commission during the period from 1977 through 1979. Jerry Jackson and Robert Lann adapted the model for the New York State Energy Office and the Northwest Power Planning Council (NWPPC) in the early 1980s (Jackson and Lann 1982). Very similar in structure was the original COMMEND model developed for EPRI (Lann et al. 1985). The PNL model, developed in the mid-1980s, was based on the NWPPC and COMMEND models, using revised and updated national-level data. Jerry Jackson has maintained his involvement with commercial sector modeling and currently operates the CEDMS that has been adopted by a number of utilities and power pools.

Regional Economic Research, under the direction of Stuart McMenamin, has been primarily responsible for the most recent versions of COMMEND that operate on a PC. Version 3.2 was released in early 1991 (Regional Economic Research 1991).

3.2 Overview of End-Use Model Structure

The commercial end-use models based upon ORNL's work in the late 1970s share a common framework. The disaggregated approach of these models generate projections of energy consumption by end use, fuel type, and building type. The stock of energy-using capital is measured by floor space. End-use consumption per square foot of floor space is estimated for a base period and then modified through the forecast, by period, by changes in energy prices and technology availability.

The basic causal linkages in these models are shown in Figure 3.2. This figure is reproduced from the original 1985 COMMEND model documentation (Lann et al. 1985). The top left portion of the figure represents the floor space submodel. The principal variables driving floor space in these models are employment, population, and income. The choice of specific variables depends on the building type.

Two basic approaches have been applied to projecting floor space. In the floor-space-per-employee (or per-activity) approach, the stock of floor space is projected directly from

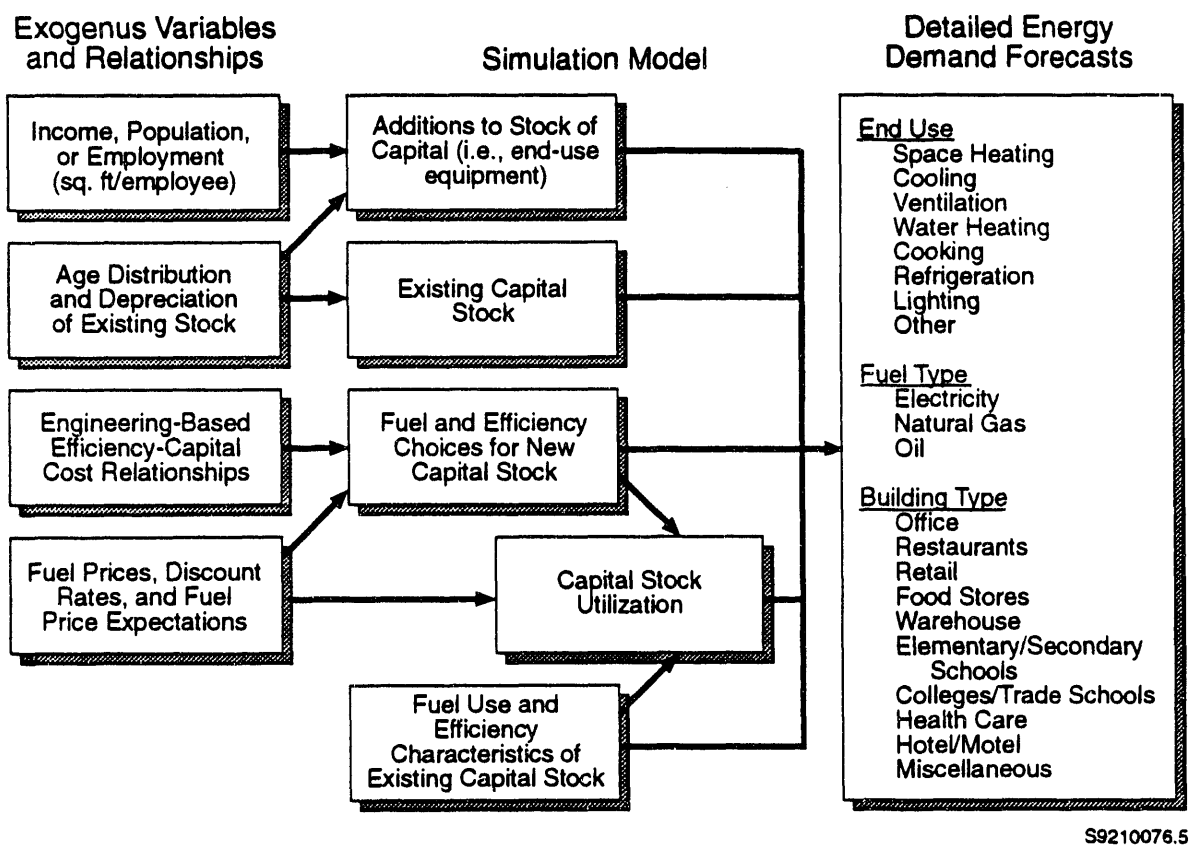

Figure 3.2. Generic Commercial End-Use Model Structure (Source: Lann et al. 1985)

a simple equation using the employment or activity variable. In this method, additions to stock are inferred from the year-to-year stock changes. In the investment demand approach, additions to floor space are projected directly. The stock is adjusted each year by adding the additions and deducting estimated removals (demolitions and residential conversions).

All of the new floor space requires new end use systems. Estimates of average equipment lifetimes are used to estimate the demand for replacement systems in existing buildings. The models keep track of the age distribution of existing end-use systems, along with their fuel use and efficiency characteristics.

The core of the models relates to their determination of the fuel use and efficiency of new systems. The most elaborate treatment involves HVAC systems. With the exception of more recent versions of COMMEND (Version 3.1 and 3.2), all of the models are based upon explicit engineering relationships between the operating (energy) cost and the initial capital costs of alternative systems. Depending on a set of economic decision-making criteria (e.g., minimum life-cycle cost, pay-back period), the firm will choose an optimal system. This choice involves both efficiency and fuel choice.

The specific engineering-economic optimization approach has been applied for HVAC and in one lighting model. Normally, the approach for these other end uses is to use a set of fuel price elasticities to project future efficiencies. (The relationship between fuel price and use is generally expressed in terms of elasticities.)

Equipment use, reflecting the intensity of equipment use, is primarily influenced by fuel price. For new buildings and replacement capital in existing buildings, use also depends on the efficiency of the equipment. In this case, an effective fuel price is calculated where improvements in efficiency can offset increases in fuel prices. Where equipment has not changed from one period to the next, use is solely dependent upon the fuel price.

The detailed energy demand forecasts shown in the right portion of Figure 3.2 are disaggregated by end use, fuel type, and building type. Generally, eight to ten end uses are distinguished, three or four fuel types, and ten to twelve building types.

3.3 Key Differences in Current End-Use Models

Although the general framework described in the previous section applies to all of the current end-use models, some significant differences exist in the way certain variables are modeled. These differences have arisen for a number of reasons: 1) data availability,

2) different calibration techniques and ex post-adjustment, and 3) attempts to reduce complexity. Some of the major differences for several major components of the models are discussed below.

3.3.1 Floor Space Stock

The principal variables driving floor space in these models are employment, population, and income. The choice of specific variables depends on the building type. In CEDMS, Jackson has included additional activity variables such as the number of hospital beds, school enrollment, etc.

Two basic approaches have been applied to projecting floor space. In the floor-space-per-employee (or per-activity) approach, the stock of floor space is projected directly from a fairly simple equation using the employment or activity variable. In this method, additions to stock are inferred from the year-to-year changes in stock.

In the investment demand approach, additions to floor space are projected directly. The stock is adjusted each year by adding the additions and deducting estimated removals (demolitions and residential conversions). For long-range projections of national floor space, the PNL commercial model has used a single aggregate additions equation using real gross national product (GNP); additions by building type are made with a shares approach. Current work by LBL with COMMEND 3.2 is directly using these projections of additions to build up total floor space. The floor space projection approaches are discussed in more detail in Section 10.0.

All of the new floor space requires new end-use systems. Estimates of average equipment lifetimes are used to estimate the demand for replacement systems in existing buildings. The models keep track of the age distribution of existing end-use systems, along with their fuel use and efficiency characteristics.

3.3.2 Equipment Choice

The major differences in the models relate to their determination of the fuel use and efficiency of new equipment. The most elaborate treatment involves the HVAC systems. In the original COMMEND formulation, Jackson's production function approach was followed to represent the tradeoff between equipment capital and efficiency. Cobb-Douglas type production functions were estimated separately for electric and gas-based (fossil fuel) heating systems. The average market efficiency of new systems was determined from a computer-generated sample of firms, whose decision-making criteria (discount rate and price expectations) are described by a population distribution. This microsimulation (Monte Carlo) approach incorporated both engineering relationships and behavioral variables.

3.3.2.1 PNL Commercial Model

As a variant of the original COMMEND model, the PNL commercial model has retained the microsimulation submodel to estimate HVAC efficiency. The fuel share aspect of this submodel, however, was changed to use an econometric function. The parameters of this function were based on a fuel shares model estimated at ORNL in 1978 (Cohn 1978).

3.3.2.2 COMMEND

The more recent versions of the COMMEND model (including the most recent, Version 3.2) have dropped the microsimulation approach in its full-blown formulation. In Versions 3.1 and 3.2, the efficiency information has been input to the model in the form of efficiency ranges (Regional Economic Research 1991). Given the base efficiency, the low and high efficiencies (in practice, intensities or energy use per unit of output are used) would be represented as factors times the base efficiency. For example, the range of heating technologies might be represented as an intensity that is 10% above the base value to a more efficient technology that used 20% less energy than the base.

In COMMEND Version 3.1, the efficiency range data were used in conjunction with decision parameters to estimate a set of reduced-form price elasticities. The price elasticities indicate the percentage decline in the average energy intensity of new electric systems as a result of a 1% increase in the electricity price.

In the more recent version of COMMEND (Version 3.2), a more explicit algorithm is used. In this version, decisions are modeled each year, given the position and shape of the efficiency range in that year. Each year the efficiency range is represented by five specific options. The positions of these options are adjusted to account for technological change, efficiency standards, and efficiency incentive payments.

Figure 3.3, reproduced from the Version 3.2 user's manual (Regional Economic Research 1991), illustrates the five-option concept in the current COMMEND model. In this example, the initial efficiency range extends 25% above the average (new) unit to 40% below the average unit. Costs are also represented in relative terms, from 20% below the average to 50% above the average. This particular example was used to demonstrate how efficiency incentive payments would be modeled in this framework. These incentives reduce the user's cost of the highest two efficiency options.

The actual choice of options in COMMEND is controlled through a set of elasticities that apply to the life-cycle cost; therefore, the elasticities provide the sensitivity of the share to the life-cycle cost of that option. In moving from COMMEND Version 3.1 to Version 3.2, the elasticity formulation has been disaggregated. One set of elasticities applies to equipment efficiency decisions, and the second set applies to fuel and

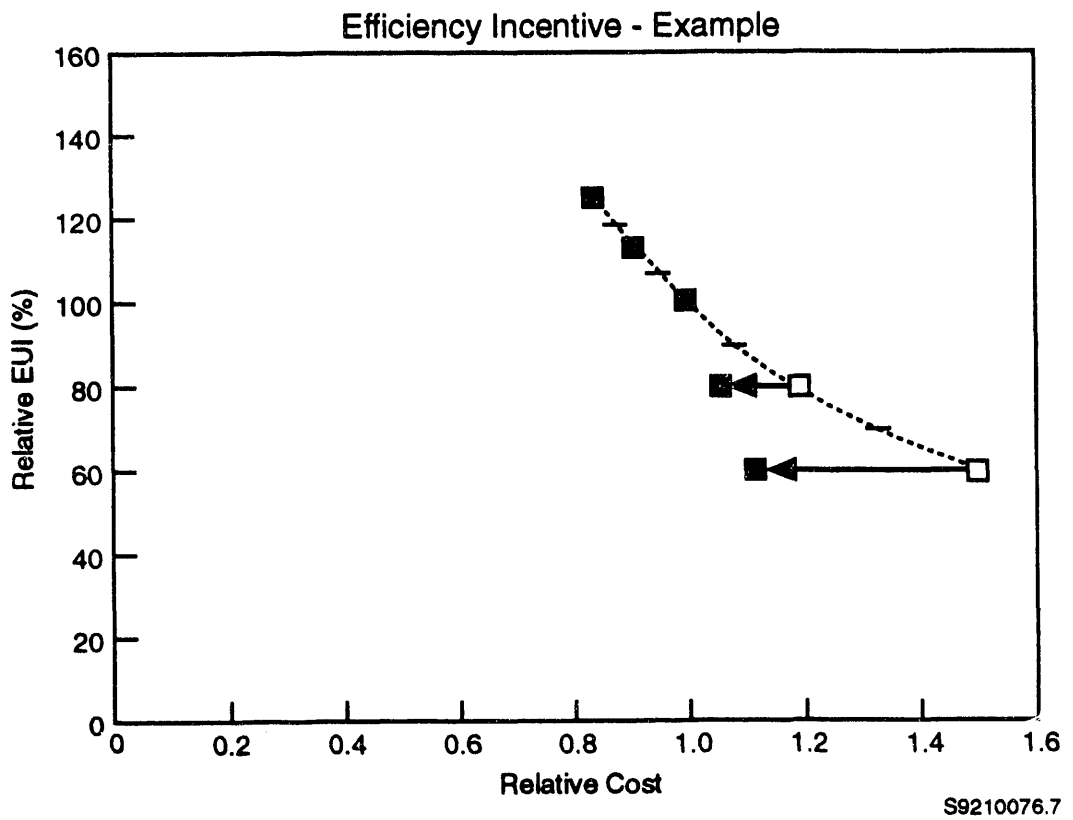

Figure 3.3. Illustration of COMMEND Efficiency-Cost Tradeoff Curve with Five Options (Source: Regional Economic Research 1991)

technology choice. As stated in the model documentation, this structure is intended to approximate the results of the "nested logit" framework, where the degree of substitutability depends upon the decision level. In COMMEND, the upper- or first-level decision relates to fuel choice. Given fuel choice, the lower- or second-level decision involves the choice of efficiency.

3.3.2.3 CEDMS

Jackson's latest version of CEDMS retains the microsimulation approach but implements a pure discrete choice algorithm.[a] Thus, in contrast to the original COMMEND model (and the similar NWPPC [Jackson and Lann 1982] and PNL models), this formulation drops the intermediate step of estimating a production function from the technology cost and performance information. Each decision maker in the Monte Carlo sample selects an

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(a) Jackson, J. R. 1988 (not publicly available). *CEDMS - PC User's Guide and Reference Manual*. Prepared for New England Power Pool (NEPOOL) by Jerry Jackson and Associates, Chapel Hill, North Carolina.

optimal technology from a limited number of technologies; the specific choice depends on the parameters corresponding to his/her own particular decision criterion. Jackson is currently using a simple pay-back criterion.

3.3.3 Model Disaggregation

The classifications of end use, fuel type, and building type vary slightly in the models. Table 3.1 shows these classification differences. Until the most recent version of the COMMEND model, the end-use breakdown in the derivative models followed Jackson's original classification; in Version 3.2, COMMEND separates lighting into interior and exterior lighting. It also breaks out receptacle loads from the "other" category.

The major change in the classification of building types was made in the PNL commercial model in 1985. This model redefined the building classification to align with the nonresidential building energy consumption survey (NBECS) information collected by EIA (1981). In EPRI's latest COMMEND model, the previous Jackson building classification was expanded to separately treat large and small office buildings.

3.4 Comparative Assessment as Related to Current DOE Requirements

This section provides a brief comparative assessment of the major existing models that could be enhanced for DOE use. An important distinction between model structure and model databases must be maintained. In some key areas, the existing models contain the structure to meet a critical DOE requirement. However, the underlying engineering or behavioral data to support the model in such areas is either judgmentally assumed or non-existent.

Table 3.2 is adapted from a list of DOE information requirements that was developed for the buildings model review meeting held in Washington, D.C., in June 1991 (see Table 2.1). DOE requirements are classified into three major areas: 1) energy policy formulation and analysis, 2) regulatory analysis, and 3) R&D programmatic prioritization.

Each subcategory in Table 3.2 indicates whether the model has strong capability (S), weak capability (W), or no capability (N). Obviously, this type of rating system is necessarily subjective. One distinguishing characteristic between strong and weak capability relates to the amount of side calculation that would have to be performed to conduct the type of analysis. Strong capability in the model structure indicates that the model would be able to provide a specific answer without additional computations. For data, these designations would involve the age and comprehensiveness.

In general, none of the models currently provide a satisfactory capability to address the types of policy and analysis needs of DOE. The strongest area in the existing models relates to describing the pattern of current energy consumption and making projections of these patterns for the future. These disaggregated forecasts can provide some upper limits on technical conservation potentials. However, the structure of the current models

Table 3.1. Disaggregation in Major End-Use Models

Classifications	Models	
	COMMEND 1.0 PNL	
	CEDMS	COMMEND 3.2
End Use	Heating	Heating
	Cooling	Cooling
	Ventilation	Ventilation
	Water Heating	Water Heating
	Cooking	Cooking
	Refrigeration	Refrigeration
	Lighting	Exterior Lighting
	Other	Interior Lighting Plug Loads
	COMMEND 1.0 PNL CEDMS COMMEND 3.2	
Fuel Types	Electricity	
	Natural Gas	
	Other	

	COMMEND 1.0 CEDMS	PNL	COMMEND 3.2
Building Types	Office	Small Office	Small Office
		Large Office	Large Office
	Restaurant	Restaurant	Restaurant
	Retail	Retail	Retail
		Auto Repair	
	Grocery	Grocery	Grocery
	Warehouse	Warehouse	Warehouse
	School	Education	School
	College		College
	Health	Health	Health
	Lodging	Lodging	Lodging
		Assembly	
	Other	Other	Other

Table 3.2. Strengths and Weaknesses of Candidate Commercial Sector Models for Policy Analysis[a]

	COMMEND			PNL Commercial			CEDMS		
		Data			Data			Data	
	Structure	Nat.	Rgn.	Structure	Nat.	Rgn.	Structure	Nat.	Rgn.
Energy Policy Formulation and Analysis Disaggregated Consumption									
- Current	S	W	N	S	S	N	S	N	S
- Forecast	S	W	N	S	W	N	S	N	S
Floor Space	S	N	N	S	S	N	S	N	S
Conservation Potential									
- Technical	W	N	N	N	N	N	S	N	W
- Economic									
- Benefits ($)	N	N	N	N	N	N	N	N	N
Demand Elasticities	W	W	N	W	W	N	S	N	S
Regulatory Analysis									
Energy Savings	W	N	N	N	N	N	W	N	N
Economic Benefits	N	N	N	N	N	N	N	N	N
Compliance Rates	N	N	N	N	N	N	N	N	N
R&D Prioritization									
Energy Savings	W	N	N	N	N	N	S	N	W
Economic Benefits	W	N	N	N	N	N	W	N	W

(a) S = strong capability, W = weak capability, and N = no capability.

cannot presently be used to make a realistic estimate of either technical or economic conservation potential. All of the models contain the elements to indicate how future consumption might change in response to changes in fuel prices. This capability, of course, can be used to examine the impacts of various fuel tax policies.

The lack of technology detail within the energy accounting frameworks of these models inhibits their use for R&D program assessment. The COMMEND framework provides the structure to examine technology trends; however, the implementation makes it difficult to specify technologies with specific cost and performance characteristics. The structure in CEDMS does not share this problem; it suffers only from the lack of a comprehensive engineering-oriented database to support a baseline energy projection.

This situation, with regard to standards, is only slightly better. COMMEND contains the flexibility to incorporate equipment standards, with and without assumed trends in technological change. However, in a recent study of the DOE lighting initiative (Atkinson et al. 1992), LBL found this flexible structure to be incapable of handling the complexity of

real-world standards. In particular, the model could not address the issue of component standards (e.g., lighting standards pertaining only to ballasts). CEDMS is more amenable to equipment standards because it includes specific technology options. Both models treat thermal efficiency standards in a very simplistic fashion. The PNL model, while including code for thermal efficiency standards, has never been exercised to test that capability.

In the following section, each of the models is discussed in more detail. In addition to model structure and data issues, the general availabilities and software compatibilities of the models are discussed.

3.4.1 COMMEND

COMMEND has undergone continual revisions since its development by EPRI in the mid-1980s. In 1987, it was substantially revised by Regional Economic Research. The major revision involved simplifying the production function-based technology-choice module originally developed by Jerry Jackson. This revision was intended to make the introduction information for model efficiency and cost more transparent.

The continued support of EPRI has produced a model that can meet the off-the-shelf requirements of member utilities. In general, the model structure has emphasized robust relationships for divergent situations in various utilities and straightforward model relationships. Member utilities can obtain the model code with a default set of parameter values.

The off-the-shelf requirement has lead to a model that contains a comprehensive user interface. Various menus are used to change model parameters. While simplistic, the model output can be graphically displayed, although hard-copy capability is not yet available. Several sets of the user's manuals for the model are available.

As mentioned above, LBL has recently used to the model to examine various strategies associated with the DOE lighting initiative. Osman Sezgen, who was responsible for the modeling efforts with COMMEND, prepared a memorandum that summarizes some of critical needs identified in that project.[a] The discussion below is based on the important points of that memorandum.

One of the key issues raised by the LBL work was the representation of technologies in COMMEND. This work pointed out the weaknesses of choosing the five technology options along a crudely estimated cost-efficiency tradeoff curve. These five options may bear no relation to actual technology options available in the market. As mentioned above, the LBL work found the model unable to handle components of technology options. As

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(a) Sezgen, O., and M. Lecar. Personal memo, dated January 1, 1992, to J. Koomey, M. Levine, and E. Peterson.

the overall result, Sezgen writes, "The major problem with this type of modeling, it is very difficult, if not impossible, to estimate what the potential for new and efficient technologies at a given time for new buildings or existing buildings are."

The LBL work pointed out the simplistic treatment of shell measures in COMMEND. Although percentage improvements over the baseline can be specified in Version 3.2, the code is inadequate to represent a typical code such as ASHRAE 90.1 (ASHRAE/IES 1989).

COMMEND models technology choice on the basis of minimum discounted life-cycle cost and an assumed elasticity of the responsiveness of decision makers. The LBL memorandum expresses concern with this representation and suggests that alternative formulations be examined (e.g., pay-back criteria).

Another weakness of COMMEND, although not unique to this model, is the lack of any accounting for capital and fuel costs. This deficiency forces the user to conduct the economic cost-benefit calculations outside of the model structure. For policy analysis, improvements to COMMEND in this area are essential.

LBL identified a number of data-related issues. The current default data for fuel shares and end-use intensities (EUIs) are based on the 1983 NBECS. Given the existence of the 1986 NBECS and the soon-to-be-released remainder of the 1989 commercial building energy consumption survey (CBECS), this information needs to be updated to provide a current baseline. As shown in Table 3.1, COMMEND continues to basically follow the building-type classification used by Jackson. LBL notes definitional discrepancies between this classification and NBECS/CBECS that need to be addressed.

The LBL memorandum points out a number of technical limitations of the current COMMEND model; however, some critical access issues also need to be considered. First, COMMEND is available only to government agencies and government-owned, contractor-operated facilities at a nominal charge. For other agencies (including the Battelle-operated PNL and perhaps some of the other national laboratories), the licensing fee is $20,000.[a] This would severely limit the use of the model by potential private reviewers and possible contributors.

Second, there is issue of further model development. DOE and the supporting laboratories will need access to the source code to make model enhancements. Although we would not preclude the use of EPRI and its prime contractor, Regional Economic Research, Inc., in performing some of these enhancements, we believe that the laboratories also

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(a) For PNL and other laboratories that fall into the same classification, the model might be obtained through DOE for specific analysis projects. We are still investigating the legal aspects of such usage.

need to be involved in this process. This issue raises the question of whether the resulting model is COMMEND or an alternatively named derivative. LBL intends to explore some of these issues with EPRI.

Finally, there is the perception issue of whether an EPRI-sponsored model can be used for national energy policy analysis. LBL understands that in the case of the appliance standards analysis, there is no legal barrier for use of a proprietary model. However, COMMEND is not only proprietary, but is also supported by a single industry association. That still leaves the question of whether the model, in its current state, could be widely viewed as completely objective, both within DOE and by various energy-related public interest groups. This perception issue could inhibit potential future use of the model within DOE at large.

3.4.2 CEDMS

The CEDMS model maintained by Jerry Jackson probably has the most complete structure to address various policy areas. Jackson has built a structure that can be calibrated over an entire historical period. This calibration procedure should enhance the pure forecasting capability of the model, particularly its responsiveness to potential fuel price changes. As part of the calibration process, some insights into the short-term use of elasticities can be gained, as well as various biases that influence fuel choice. Unfortunately, some of the information used by Jackson in the calibration comes from detailed utility audits. To duplicate this process on a national scale may not be feasible from DOE's point of view.

The strongest part of the CEDMS structure relates to its use of specific technology and cost data in its efficiency and fuel choice submodel. This structure would lend itself most readily to assessments of OBT-supported R&D. Such assessments could not be made without a substantial number of additional building energy simulations. The technology database in the current CEDMS involves only a limited number of HVAC and lighting options. Consideration is not given to shell measures (e.g., improved windows, roofs, etc.). Moreover, the simulation work would need to be expanded to include other climate regions in the United States.

Although CEDMS contains provisions for building standards, the implementation does not appear to be as detailed as in COMMEND. Variables are designated to represent constraints that must be met by the end-use equipment placed in new building during the starting year of the standards program. It is not clear whether there is a model standards provision relating to the building envelope.

The biggest obstacle in using CEDMS is the proprietary issue. Jackson does not sell the model code alone or even suggest that it can readily adapted to particular service

areas. Rather, CEDMS is a tool to assist the consulting and contract work by Jerry Jackson and Associates. CEDMS is used in individual utility implementations where model relationships are estimated with service area data to the extent possible. Accordingly, a national set of default values does not exist, as for COMMEND.

3.4.3 PNL Commercial Model

Unlike COMMEND and CEDMS, the PNL commercial sector energy model has received minimal development attention over the past few years. The floor space additions and stock information have been recently benchmarked to the 1989 CBECS. The aggregate floor space projection equation has also been updated. The revised floor space data were used by LBL in COMMEND to support the DOE lighting initiative work in 1991.

As a derivative of an earlier version of the Jackson end-use model, the PNL model has maintained the Cobb-Douglas production function approach to efficiency choice, which makes the current model structure unsuitable for R&D program analysis. Standards can be modeled in a limited fashion; however, there is no concept of a range of efficiencies for a specific end use at a given point in time. Thus, one must estimate the effect of standards on average efficiency outside of the model framework.

A stream-lined version of the model was recently changed from FORTRAN to a highly efficient matrix programming language, GAUSS. This change achieved approximately a 50% reduction in run time. The matrix programming language lends itself very well to the accounting framework of the model and has also been applied in testing a discrete choice technology algorithm (see Section 5.0). These developments could provide the core for a tightly coded, efficient enhanced commercial model.

3.4.4 Conclusions

Each of the models reviewed above contains aspects that would be desirable for policy modeling by DOE. As a basis for near-term use by OPA in broad policy analyses either in a stand-alone mode or a part of an integrating model, the best choice appears to be COMMEND. With many limitations, COMMEND contains the most up-to-date set of national default data, and it contains adequate documentation and a reasonable user interface. Although the technology representation for COMMEND cannot be used very effectively for program or regulatory analysis, the empirical basis for the efficiency-cost curves may provide reasonable price responsiveness for aggregate analysis.

The role of COMMEND as a starting point for CE's enhanced model is still dependent on whether the proprietary and access issues can be satisfactorily resolved. Without such resolution, the accounting structure in the PNL model could be enhanced with minimal

effort. The major issue would be the design of a user interface that would satisfy the stand-alone user, as well as those involved with the development of the integrated model.

Although CEDMS, per se, could not be used as the basis of the enhanced model, we suggest in Section 4.0 that some of its key features be adapted for use in such a model. At some point, CE may wish to examine the energy forecasting properties of the enhanced model. Here, the experience of Jerry Jackson in various utility applications would be invaluable. Because of these factors, we would recommend that Jackson be involved (to some degree) in future model development activities.

We emphasize again that none of the current models can at this time meet the various policy analysis and program planning needs within CE. The largest deficiency is the lack of credible supporting information on specific building technologies, including estimated costs and interaction effects. Only detailed building energy simulation studies can provide this information. The following section addresses this issue in more detail. The intent is to lay out a more comprehensive vision of what would comprise an enhanced commercial sector modeling system that could address future analysis needs within CE.

4.0 Overview of Enhanced Commercial Sector Energy Model

This section describes the framework of an enhanced commercial sector energy forecasting and policy analysis model for use by CE. This model would remedy limitations of the existing commercial models for policy analysis and technology evaluation by various offices within CE. Financial support for the model would be structured to maintain the model in the public domain but under CE's general control.

The first portion of this section describes the proposed model structure. The structure is described only in broad terms of its intended final form. The actual development of the model will likely begin with one of the existing energy-accounting-based models described in this section.

In subsequent sections, we provide additional details concerning the various components of this model structure. After the model is generally described, its potential types of use within CE are indicated. Finally, the general level of effort and the schedule to complete an initial version of the model are discussed.

4.1 Structure of Proposed Commercial Sector Modeling System

Figure 4.1 provides a broad overview of the proposed commercial sector forecasting tool. For labeling purposes within this report, we have termed the analytical components of this tool the COmmercial Sector Energy Modeling System (COSEMS). Conceptually, COSEMS consists of three components: 1) a database of exogenous variables, 2) one or more building energy simulation models, and 3) a sectoral energy accounting and forecasting model.

COSEMS differs from existing commercial energy models in its recognition that the engineering-based building energy simulation tools are an integral component of the overall energy forecasting capability. This implies that the definition of prototypical buildings and the operating characteristics of such buildings become important issues from an overall modeling viewpoint.

COSEMS would be designed from the outset to consider discrete identifiable technologies to the greatest extent possible. The model would be designed to look at discrete envelope and HVAC technologies, as well as lighting. Thus, the model would go beyond the discrete technology choice framework for lighting used in the current CEDMS model. Each of the COSEMS subsystems is discussed below.

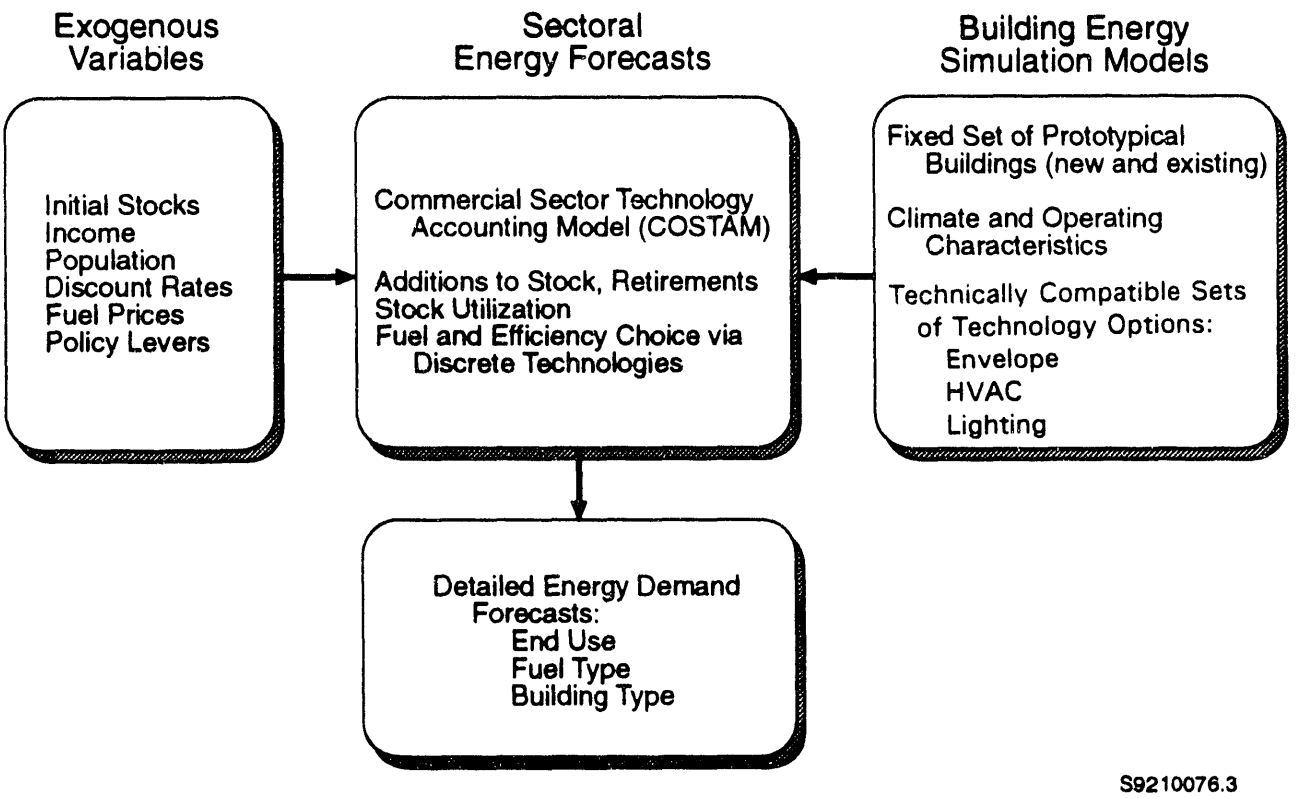

Figure 4.1. Overview of Commercial Sector Modeling System (COSEMS)

4.1.1 Exogenous Variables

Developing a database of exogenous variables (e.g., income, population, and fuel prices) would not differ greatly from the approach used in the existing commercial models. Important guiding principles are 1) compatibility with other analytical tools and models within DOE, and 2) the need to provide a valid statistical representation of commercial buildings in the nation as a whole. An example of such consistency would be the use of the NBECS and CBECS building survey information to characterize the initial stock of commercial buildings.

Income and population variables would be defined to be consistent with the same variables in the EIA (NEMS) modeling framework or the CE-integrated model. As in the current commercial models, discount rates or required pay-back periods would generally be based on fragmentary evidence from various existing studies.

A difficult challenge will be to design a set of policy levers that can be easily used. The easiest policies to implement from a modeling standpoint are financial incentives, such as fuel taxes or equipment subsidies. Unfortunately, these policies are not likely to be

adopted by the federal government in the foreseeable future. DOE's involvement in promoting energy conservation in buildings has generally been in developing more efficient technologies or in promulgating energy-efficiency standards. Building standards, such as those found in the recent DOE-supported ASHRAE 90.1 standard (ASHRAE/IES 1989), are very complex and are difficult to quantify without extensive building simulation studies. Development or accelerated adoption of advanced technologies must be considered on a case-by-case basis.

4.1.2 Building Energy Simulation Models

As stated above, we view the choice and use of building energy simulation models as an integral part of the overall modeling system. These models simulate the energy use of a specified building, normally over an annual time period. Perhaps the best known and most widely used model of this type is DOE-2, developed by LBL in the mid-1970s.

Because these models analyze specific buildings, a critical issue is how to define a set of prototypical buildings that will adequately represent the stock of existing or new buildings. How many prototypical buildings should we use, and on what basis should they be defined? In addition to the physical characteristics of these buildings, we need to cover a range of climate and operating conditions. This is an issue that has not received a great deal of attention in prior commercial sector forecasting models. This issue is discussed in more detail in Section 8.0.

The role of the building simulation models is to generate energy performance measures for a variety of possible technology options for the prototypical buildings. In general, packages of options will be evaluated via the simulation tools. It is expected that professional judgement will be applied to limit the number of packages to those that have best chance of being used in actual buildings. At a minimum, this implies that the technologies considered are technically compatible. For example, we would not expect to find tinted windows in conjunction with expensive daylighting controls; the tinted windows may not transmit enough visible light into the building for the electric lights to be dimmed.

The building energy simulation models themselves do not incorporate economic optimization features. The menu of simulations used to support previous commercial models has generally been guided by professional judgment concerning the economic viability of various building technologies. For example, central chillers would not be considered for small buildings because their high initial cost would not be recovered over the life of the equipment. In the past, the high computing costs of these models, as well as the effort to construct various packages of options, have generally resulted in the consideration of a limited number of basic technological options.

Several CE-supported programs are currently under way that will lead to analytical tools that will explicitly incorporate economic optimization to select the most cost-effective set of options for a specific building configuration. The Whole-Building Energy Targets Project (supported by OBT) focuses on new buildings. The project is currently developing procedures to allow a number of building simulations, using existing building energy models, to be run without user intervention and an optimal set of options to be identified. To analyze building retrofits, an optimization procedure incorporating building energy simulation is being developed to support energy conservation planning in federal facilities. The analytical tool, labeled as Federal Energy Decision Screening (FEDS), is being supported by the Federal Energy Management Program (FEMP) office within OBT. We provide an overview of both of these efforts in Section 9.0.

These optimizing simulation models could substantially reduce the staff time required to generate various packages of technological options. As part of COSEMS, these models could automatically generate optimal efficiency levels for a pre-determined schedule of fuel prices. As discussed in Section 4.0, both fuel choice and efficiency can be addressed in this framework. A database of technology packages would be generated from these models for use as input to the broad-sector energy accounting and forecasting program.

4.1.3 Energy Accounting and Forecasting Model

The core of COSEMS, as depicted Figure 4.1, is the energy accounting and forecasting model. We have tentatively given this model the acronym COSTAM (COmmercial Sector Technology Accounting Model). COSTAM serves the same role as current commercial sector models (such as COMMEND and CEDMS) described in the previous section.

COSTAM has three general functions. The first function of COSTAM provides a means of accounting for the simulation results from the prototypical buildings. The objective is to make the aggregate results depend entirely upon the results of the prototypical building simulations. Each prototype building would be assigned a weight representing the share of total floor space of that type of building in the population. As part of the aggregation system, COSTAM also adjusts the weights of the prototypical buildings representing existing stock to account for demolitions. The model must also handle replacement of energy-using equipment in existing buildings. New floor space is projected via relationships to income and demographic variables. The projections of future floor space must then be used to assign weights to prototypical new buildings.

The second function in COSTAM is to account for short-run changes in using existing stock. These relationships have generally been specified in the current commercial models in terms of price elasticities. This is probably the most cost-effective approach from a model-development standpoint. These elasticities can be adjusted if historical model calibration exercises are performed.

The third and most important function of COSTAM is to provide a technology choice framework. Choices are made from a menu of discrete technologies, each with information on fuel use, initial capital costs, and expected lifetime. These menus of discrete technologies (or packages of technologies) are provided to COSTAM from a database of prototypical building simulation results. The technology choice module would simultaneously address fuel choice and efficiency choice.

The economic criteria for decision choice involves some type of life-cycle cost minimization or simple pay-back analysis. In this respect, the proposed model would generally follow the approach of existing models. In the next section, we illustrate the basic approach following the pay-back period method used by Jackson.[a]

4.1.4 Model Output: Detailed Demand Forecasts

At the aggregate level, the outputs from COSTAM are similar to the existing commercial models. Energy consumption for the nation (or a region) can be categorized by end use, fuel type, and building type. Beyond the existing models, the discrete choice framework will provide additional information regarding the adoption of specific technologies. Not only can the model indicate the rate of technology penetration, but it will also suggest the types of buildings where new technologies are most likely to be adopted first.

An economic accounting framework will also be included within COSTAM. This framework would keep track of the costs of equipment and retrofit activities. These costs would also be converted to an annualized basis, which would permit a calculation of the cost of conserved energy from a comparison of two model simulations.

4.2 Anticipated Policy Analysis Capabilities of COSEMS

The structure described above would be able to provide insights on a number of policies that the DOE might undertake in the future. As compared with the existing models, the proposed structure (with its strong emphasis on identifiable technologies) would provide the greatest assistance in R&D planning. However, the proposed model would have sufficient structure to examine conservation programs involving efficiency standards and financial incentives.

(a) Jackson, J. R. 1988 (not publicly available). *CEDMS - PC User's Guide and Reference Manual*. Prepared for New England Power (NEPOOL) by Jerry Jackson and Associates, Chapel Hill, North Carolina.

4.2.1 R&D Planning

The COSEM system can be used for many types of analyses that can assist with R&D planning. This capability would be of particular use to OBT.

4.2.1.1 Defining the Market for a Known Technology

One of the most straightforward planning applications of COSEMS would be to identify the types of buildings in which a potential new technology would be most cost-effective. In concept, any piece of equipment or building component, whose performance and cost can be quantified, can be included as option in optimizing (in COSTAM and possibly in the advanced building simulation tools mentioned above). The overall system can indicate the building types and locations where the technology would be most likely to be adopted.

4.2.1.2 Characterizing Economic Viability

Various measures of the economic attractiveness of specific technologies can be constructed from the model output. One such measure would be the savings-to-investment ratio (the ratio of life-cycle savings to initial capital costs). This ratio can be examined over various building types and locations to indicate the magnitude of the economic incentive for adopting the technology.

The optimization framework within the complete system ensures that the measures of economic viability account for interactions among related technologies. As an example, an advanced glazing may not have the same economic attractiveness over a conventional glazing when relatively inexpensive daylighting controls are available.

4.2.1.3 Characterizing Potential Market Penetration

The accounting framework within COSTAM allows a way to estimate market penetration of new technologies. The model projects the level of new construction in which many technologies have the greatest probability of being adopted. The model also accounts for turnover of equipment in existing buildings, which can also represent opportunities for adopting new technologies. An extension to the model is to link production costs to the level of output. As the market for a new technology increases, its costs fall, leading to additional market penetration.

4.2.1.4 Characterizing Potential Impact

The overriding objective of OBT remains to promote energy conservation--specifically energy efficiency--in the nation's homes and commercial buildings. Energy savings become the paramount criterion in evaluating particular policies and research programs.

COSEMS will provide a way to measure energy savings for a specific technology as well as providing a research program that encompasses a number of technologies. The perennial problem of double counting savings from related technologies will be mitigated in the system described above. The whole-buildings approach, combined with an energy-feature optimization, will take account of the interactions among various technologies.

The use of cost estimates for specific technologies also implies that the aggregate cost of energy savings can be computed. This cost can be compared with supply side options, including imported energy.

Finally, although energy savings are a paramount criterion in program planning, environmental concern related to energy use continues to grow. The model can be easily adapted to show the environmental residuals (CO_2 and pollutants) associated with particular research agendas.

4.2.2 Energy Standards

After R&D, the largest conservation activity related to buildings within OBT involves energy standards. Since the late 1970s, DOE has been tasked by Congress to promulgate energy-efficiency standards related to equipment. DOE has also been involved in developing the technical basis for various building standards.

The general approach in evaluating standards in COSEMS is to identify the subset of current technologies that would not meet a particular standard. In the technology choice module, these technologies are deleted from the menu of choices. Average efficiency will increase after standards are adopted, the magnitude of which depends upon the distribution of efficiencies sold prior to standards.

The general approach described above works best with equipment where specific models of varying efficiencies and costs can be included in technology choice algorithm. This approach has been used in recent versions of LBL's residential energy model, LBL-REM. The approach becomes more difficult to apply in the performance-based building standards. Here, we must be very careful to identify packages of options that represent the current practice (not meeting the proposed standard) and more efficient options that exceed the standards.

In spite of this difficulty, the comprehensive structure of COSEMS should more adequately handle the complexities of standards, as opposed to the very simple treatment of standards in the existing commercial sector models. The building simulation models will be an integral part of the proposed modeling system. As such, these models can reflect the way the standards are actually written, rather than resorting to simplistic proportional adjustments, whose magnitudes must be input to the model (e.g., COMMEND

Version 3.2). For example, the building simulation models can translate a lighting budget, in installed watts per square foot, into annual energy savings. The building simulation models will also account for end-use interactions.[a] The set of prototypical buildings will also provide a basis for estimating how the interactions may differ among building types, operating conditions, and climates.

4.2.3 Financial Incentives

The overall modeling framework can also be used to analyze various financial incentives and disincentives, including fuel taxes, equipment tax credits, rebates, grants, and special financing arrangements. The overall model can estimate the energy savings and tax revenue implications of these policies. The impacts, at least in terms of energy savings, of such policies can generally be assessed with existing commercial models (e.g., COMMEND). For these policies, COSEMS would indicate what types of technologies would be favored under various incentive policies. This capability could be exploited for analyzing joint policies that used DOE funding to develop a specific technology and incentives to accelerate its adoption.

4.3 Approach to Developing Improved Commercial Model

The development of COSEMS, as depicted in Figure 4.1, is an ambitious undertaking. Similar to the ORNL-developed models of the 1970s, such an effort would be a multi-year effort involving a variety of disciplines, including economics, engineering, and computer science.

At the outset we need to be clear what is implied by a new modeling framework. First, as compared with the existing commercial models, COSEMS would explicitly incorporate the analytical capability embodied in one or more building simulation codes. This feature allows end use and technology interactions to be analyzed in a rigorous manner and in such a way that the aggregate energy implications can be estimated automatically. In some of the more limited accounting models now available, these interactions are entered into the model in an ad hoc manner.

The currently available models still require engineering-based cost and efficiency relationships as exogenous inputs. As indicated in the previous section, adopting one of the existing models does not imply that these relationships are up-to-date or represent typical buildings. Moreover, the accounting-based models alone cannot perform the

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(a) COMMEND includes this interaction as a model input. Presumably, an average interaction effect is based upon prior building simulation studies. In COSEMS, the building simulation tool is considered part of the overall modeling framework.

engineering-based evaluation of new DOE-funded technologies. COSEMS would include this capability as part of its overall framework; the accounting and engineering simulation tools would be designed from the outset to complement each other.

Second, as mentioned at the beginning of this section, a new model does not mean that we are starting from scratch; it will still be cost effective to begin from an existing model. The two most likely candidate models are the COMMEND model or PNL's existing commercial sector model. The computer code from an existing model must be revised and extended to generate COSTAM. COSTAM must provide a means for selecting technologies and for tracking vintages of technologies. These concepts have been implemented in CEDMS and industrial technology models. The additional coding of the new accounting model is not expected to be a major task in the overall model development.

Finally, completing the enhanced model does not imply that 100% dedicated funding is required. Within OBT, several ongoing projects could provide technical inputs to the proposed model, such as the Whole-Building Energy Targets Project and FEMP-related models (FEDS) discussed above, as well as the Building Energy Standards Program. A general strategy is to use dedicated model funding to produce those portions of the model that would not be of direct interest to any of these existing programs.

The proposed model would be under direct control of CE and would not be under the proprietary restrictions of several of the existing commercial models (e.g., COMMEND and CEDMS).[a] As mentioned in Section 3.0, this does not rule out employing concepts from these models, perhaps implemented by the model developers themselves.

Without discussing schedule and budget in specific terms, the key task areas that will be required to create an operating version of the system are prioritized below.

4.3.1 Cost-Efficiency Database

The fundamental information gap in developing a technology-based commercial modeling system is a credible cost-efficiency database. Although a wide variety of cost estimates are available for various technologies, these have generally been collected on a case-by-case basis for specific utility conservation programs. Valid cost information, including installation in both new and existing buildings, is essential to support the economics-based technology choice framework.

(a) If COMMEND is chosen as a starting point, some method will be required to transform it into public-domain status. At this point, it is not clear what approach would be best for achieving this.

Developing a cost database is of interest to a variety of programs within CE and OBT. LBL is currently tasked with developing conservation supply curve for office buildings, a project that demands generating cost information. The targets and FEDS building simulation models currently under development require information on component and equipment costs. Economic evaluation of building standards also requires cost information. Finally, if the model is to be used to aid R&D planning in OBT, some idea of costs for advanced technologies will be needed.

A current method does not exist to collect such costs or procedures to ensure statistical validity of the costs (i.e., how large a sample should be used to determine an average cost). Moreover, a database structure is required that will interface easily with any choice of building simulation code. Also, one or more private sector building cost estimator tools might be needed to assist in this effort.

4.3.2 Development of Prototypical Buildings

Developing a set of prototypical buildings is perhaps the next priority. These buildings provide the framework for the building simulation analyses. The choice of such buildings may, in turn, influence the choice of the building simulation tool.

Work at LBL and PNL has addressed this issue in the past and can be used as a starting point to develop a generally acceptable set of buildings. The commercial standards program currently has a keen interest revising and extending the set of prototypical buildings used in the engineering simulation work. Ideally, a single set of prototypical buildings can be defined that would be satisfactory for a number of analytical efforts within CE and OBT.

4.3.3 Generation of Technology Options

Estimating the energy consumption of various technology packages can be performed by a number of building simulation models. These packages will be ordered in terms of increasing efficiency and cost. This task is to select a limited number of simulation models that will be used to perform this work. In addition, general guidelines must be established as to how various technologies are packaged together. This work can build upon ongoing work at LBL to construct a supply curve for the office building sector and work at PNL to look at the boundaries for new commercial building standards.

The result of this task should not be to fix upon a certain simulation model for exclusive future use. As mentioned above, using simulation codes containing optimizing features in themselves is likely the preferred development strategy for the long run.

4.3.4 Development of COSTAM

To implement the technology accounting and choice framework, the computer code for COSTAM must be developed. Our preference is to build on a current accounting-based model (using building-type floor stock and energy intensities), either a version of COMMEND that can be put in the public domain or the commercial model that has been used by PNL for OBT to generate baseline energy projections. Either of these choices would incorporate a basic accounting structure for building and equipment additions and replacement. The technology choice module can build on exploratory work recently done at PNL (see Section 5.0).

5.0 Equipment Efficiency and Fuel Choice

At the core of the proposed model's handling of efficiency and fuel choice would be a discrete choice approach similar to the present CEDMS model. Specific technologies with associated performance characteristics and costs would be evaluated against a given economic criterion. The optimal technology will dictate the fuel used as well as the technical efficiency.

For modeling purposes, we need to distinguish between a single decision and a market outcome, which encompasses the choices of many decision makers. In a discrete choice model, if the market outcome is the result of the average or typical economic criteria, only one technology is being chosen. Even after ignoring the issues of fuel availability and incomplete information, this result is not consistent with observed market behavior.

Jerry Jackson's approach to representing a market outcome has been to employ a Monte Carlo-based simulation for a sample of firms. This approach is currently employed in CEDMS and was in Jackson's models for EPRI and the NWPPC. The population of firms is represented by one or more probability distributions of economic decision criteria and other attributes. The attributes of a single sample firm is generated by the computer by "draws" from each distribution. The variance in these distributions gives rise to a distribution of technologies chosen by the sample firms.

In the model for the NWPPC, the sample was derived from probability distributions of two attributes: 1) discount rate (hurdle rate), and 2) expected fuel price escalation. In CEDMS, the process has been simplified to consider only a simple pay-back criterion. A mean pay-back period is specified with other parameters that indicate the variance of pay-back criteria around this mean. The sample size can be varied within the limits of acceptable run times for the model. In the NWPPC's model, the distribution of HVAC systems for each vintage and building type was based on a sample of 25 hypothetical firms.

5.1 Numerical Illustrations

Several numerical illustrations should make clear how the Monte Carlo approach is implemented, as well as point out some relevant issues. The first illustration focuses only on technology choice and sample size. The second illustration examines how the procedure is extended to handle fuel choice.

5.1.1 Technology Choice

An illustration of technology choice is motivated by cost and efficiency data presented in Jackson's user's guide for the NEPOOL.[a] Table 5.1 shows electricity use and cost for an office building using the current building practice.

To motivate our example analysis, we use as an economic criterion, a simple five-year payback. We then determine which system (i) yields the minimum total cost (TC), computed as the sum of system cost and five years of energy cost:

$$TC(i,pb) = SC(i) + e(i,t) + e(i,t+1) \ldots e(i,t+pb-1) \qquad (5.1)$$

where TC(i,pb) = total cost for system, i, for pay-back period, pb

SC(i) = system (capital) cost for system, i

e(i,t) = energy cost for system, i, in year, t

pb = length of pay-back period.

Table 5.1. Office Heat Load Analysis

System[a]	EUI (kWh/sq. ft) Heat	Air C	Vent	System Cost $/sq. ft
Base	7.83	3.59	1.41	7.75
+ Economizer	7.83	1.79	1.38	.24
+ Heat Recovery	6.44	1.79	1.38	.58
+ Double Bundle	6.34	1.79	1.46	.75
+ Chiller Effic.	5.73	1.59	1.46	.82
Heat Pump	9.75	3.30	.58	8.91

(a) The "+" symbol indicates that the cost of the system equals the base cost, the current cost increment, and the incremental cost of the additions listed above.

(a) Jackson, J. R. 1988 (not publicly available). *CEDMS - PC User's Guide and Reference Manual*. Prepared for New England Power Pool (NEPOOL) by Jerry Jackson and Associates, Chapel Hill, North Carolina.

Let us begin by considering the optimal system if the average electricity price is $0.08/kWh. Given this price of energy, column one of Table 5.2 shows the total cost for each system over the assumed five-year outlook. Column two shows the annual energy consumption for each system.

For a single decision maker using the simple five-year pay-back criterion, the optimal system is achieved by adding an economizer to the base system. According to the third column, this system will reduce annual energy consumption by 12%.

Now let us apply Jackson's Monte Carlo approach to this example. Two other assumptions are required: 1) sample size and 2) the distribution of pay-back periods to characterize the market. For this example, we consider a sample of 100 firms and a sample of 500 firms. The distribution of pay-back criteria is taken as a normal distribution with mean of 5 and standard deviation of 1. The normal distribution implies that about 97% of the firms analyzing these systems would have required paybacks from three to seven years.

The Monte Carlo techniques always have an issue of replicability and precision. The variance of the results is a function of the sample size. Larger samples reduce the dispersion of results at the cost of longer computing times. For complicated applications, this issue can only be addressed empirically. Repeated samples of various sizes are drawn, and the variance of the results with different sample sizes is compared. To provide a flavor of this approach with this particular application, we examined the results with samples of 100 firms and also with 500 other firms (see Table 5.3).

Table 5.2. Total Cost and Energy Consumption by System

System[a]	Total Cost Five-Year Outlook ($/sq. ft)	Annual Energy Consump. (kWh/sq. ft)	EUI Index (Base = 1)
Base	12.88	12.83	1.000
+ Economizer	12.39	11.00	0.857
+ Heat Recovery	12.45	9.61	0.749
+ Double Bundle	13.15	9.59	0.748
+ Chiller Effic.	13.65	8.78	0.684
Heat Pump	13.56	11.63	0.907

(a) The "+" symbol indicates that the cost of the system equals the base cost, the current cost increment, and the incremental cost of the additions listed above.

The top half of Table 5.3 shows the results from the samples of 100 firms. At an electricity price of $0.08/kWh, only the first three options were chosen in all simulations. Columns one, two, and three present the percentage distribution of the base system and the first two retrofit options. Column four shows the weighted average energy consumption across the three systems. Column five normalizes the numbers in column four with the base system.

Before discussing comparative results from the alternative sample sizes, we need to emphasize the general advantages of the Monte Carlo approach. Both panels show that a plausible distribution of pay-back criteria within the market would lead to a large share for both economizer and heat recovery systems. This, in turn, leads to an average efficiency approximately 7% lower than if we applied the single decision-maker framework to the entire market. The average intensity index in the Monte Carlo approach is about 0.823 (mean of 0.822 and 0.824 from Table 5.3) versus 0.86 from the single choice of an economizer system (see Table 5.2).

Table 5.3. Simulated Market Energy Intensities with Alternative Sample Sizes

Simulation Number (n = 100)	Base (%)	Base w/Economizer (%)	Base w/Economizer + Heat Recov. (%)	Annual Energy Consumption (kWh/sq. ft)	EUI Index (Base = 1)
1	5.0	50.0	45.0	10.50	0.818
2	3.0	55.0	42.0	10.50	0.818
3	6.0	62.0	32.0	10.69	0.833
4	3.0	64.0	33.0	10.62	0.828
5	3.0	48.0	49.0	10.41	0.811
Mean	4.0	55.8	40.2	10.54	0.822
Standard Deviation					0.009

Simulation Number (n = 500)	Base (%)	Base w/Economizer (%)	Base w/Economizer + Heat Recov. (%)	Annual Energy Consumption (kWh/sq.ft)	EUI Index (Base = 1)
1	6.0	53.6	40.4	10.58	0.825
2	4.	55.4	39.8	10.57	0.824
3	4.8	57.8	37.4	10.60	0.826
4	5.0	52.4	42.6	10.53	0.821
5	4.2	58.0	37.8	10.58	0.825
Mean	5.0	55.4	39.6	10.57	0.824
Standard Deviation					0.002

The Monte Carlo market simulation is advantageous because it can be calibrated to match historical data that may be available regarding the distribution of technology choices. Moreover, it can more realistically handle the introduction of new technologies. Given that new technologies are often more expensive than existing technologies, the Monte Carlo approach provides a framework for assessing initial penetration rates. With the single decision-maker approach, these technologies would be chosen only after they met the estimated decision criteria of the representative decision maker.

We turn next to the issue of appropriate sample sizes. As could be expected, the mean values are very similar across the five simulations from the both 100-firm and 500-firm sample sizes. Perhaps of most use from an energy forecasting point of view is the average intensity index. For this key metric, the average values are nearly identical: 0.824 in the 100-firm case and 0.822 in 500-firm case. The larger sample size does, however, dramatically reduce the variance associated with the index. With 500 firms in each sample, the standard deviation of the intensity index is 0.002 (less than 0.02%.) With only 100 firms in each simulation, the standard deviation is nearly 1%.

The exercise with the sample sizes shown here can only be suggestive. With another set of technology-cost data, the relative variances may be different between these sample sizes. The exercise does indicate that the modeling framework be adaptable to various sample sizes. After initial experimentation, users can choose an appropriate sample size that matches their replicability criteria and that falls within a reasonable computational time limit.

5.1.2 Fuel Choice

Fuel choice can also be directly handled by the Monte Carlo approach. Different technologies use different fuels, with associated capital and fuel costs.[a] The ultimate choice can be deemed to follow a payback or life-cycle cost criteria.

To illustrate the process of fuel choice within the Monte Carlo approach, we substituted the heat pump in Table 5.1 with a gas-fired boiler and electric air conditioner. For ease of illustration, we continue to use kWh as the energy metric; in terms of kWh, the gas-fired system is assumed to use 7.0 kWh/sq. ft for heating (gas uses more energy than the most efficient non-heat pump electric system because of combustion losses). The capital cost is assumed to be $2 greater per square foot than the heat pump (or $10.91/sq. ft.) Electricity use for air conditioning and ventilation is the same as the most efficient electric heating systems.

A series of Monte Carlo simulations was performed with an array of electricity and gas prices. Electric prices ranged from $0.04 to $0.13 per kWh. Gas prices were translated into kWh terms, ranging from $0.02 to $0.08 per kWh. While the final model would use natural units for fuels, this simplification hopefully will not detract from the salient points of the example.

(a) The differences in nonfuel operating and maintenance costs are being ignored.

Table 5.4 shows the simulated market shares (in percent) for electric heating systems. At the lowest gas price, the market share for electric systems ranges from 21% to 100%. As expected, fewer and fewer gas systems are chosen at the successively higher gas prices. Only 5% of the decision makers would choose gas at its highest price, and then only when electricity prices were $0.13 per kWh.

Note the rates of change in the electric shares as electric rate rises. In the first column, the highest rates of change occur around $0.09 per kWh. The share elasticities at both lower and higher prices are smaller. The pattern of substitution can be traced to the shape of the distribution of pay-back criteria within the Monte Carlo sample.

Table 5.5 shows the average intensity of space heating for the electric systems chosen. The key point of this table is that the average electric intensity is not independent of the price of gas. Higher gas prices generate higher average efficiencies for those electric systems that are chosen. This phenomenon can be traced to the distribution of pay-back periods that underlies the modeling approach. For the specific set of technology-cost data in this example, a falling price of gas first generates competition between the relatively efficient electric systems and gas systems. Because a larger proportion of systems would use gas instead of high-efficiency electric, this competition yields a relatively higher percentage of low efficiency electric systems among the set of electric systems. At very low gas prices, most of the few electric systems are chosen by that segment of the market with very short pay-back criteria. In this example, at the lowest gas price, the relationship of average electric intensity and electricity price is not even monotonic. Average intensity first falls with rising electric price, then increases as more and more of the higher efficiency electric systems are dropped in favor of gas systems.

Table 5.4. Market Shares for Electric Heat (office building example)[a]

Electric	Gas Price (normalized to $/kWh)			
Price	0.02	0.04	0.06	0.08
0.04	100.00	100.00	100.00	100.00
0.05	100.00	100.00	100.00	100.00
0.06	97.00	100.00	100.00	100.00
0.07	90.00	100.00	100.00	100.00
0.08	75.00	99.00	100.00	100.00
0.09	60.00	93.00	100.00	100.00
0.10	45.00	77.00	100.00	100.00
0.11	33.00	63.00	94.00	100.00
0.12	29.00	46.00	81.00	100.00
0.13	21.00	35.00	65.00	95.00

(a) Decision criteria: five-year pay-back period.

Table 5.5. Average Electric Space Heat Intensity (office building example)[a]

Electric Price	Gas Price (normalized to $/kWh) 0.02	0.04	0.06	0.08
0.04	7.83	7.83	7.83	7.83
0.05	7.77	7.77	7.77	7.77
0.06	7.73	7.69	7.69	7.69
0.07	7.63	7.51	7.51	7.51
0.08	7.68	7.38	7.37	7.37
0.09	7.69	7.25	7.19	7.19
0.10	7.68	7.16	7.00	7.00
0.11	7.83	7.17	6.93	6.89
0.12	7.83	7.38	6.97	6.84
0.13	7.83	7.43	6.97	6.81

(a) Decision criteria: five-year pay-back period.

Although the numerical examples above provide insight on how the discrete choice/ Monte Carlo approach is implemented, the results in Table 5.4 likely show more responsiveness to relative fuel price than what could reasonably expected based on historical experience. This responsiveness will be smaller, with shorter pay-back periods. Table 5.6 shows the differences in the simulated market shares when the pay-back period is changed from five years to four years.

The relatively slight difference in pay-back period makes considerable difference in the simulated shares. Over the full range of electricity price increases, the drop in the electricity share in the four-year pay-back case is roughly between 50% and 75% of the decline when a five-year rule is used. Jackson has developed calibration methods to the initially assumed pay-back period and other parameters in order to make the model better fit historical data.

5.2 Computational Issues

The Monte Carlo approach describes above is computationally intensive. For each representative building, total cost must be computed for each engineering option for each sample decision maker. The lowest cost system is then selected for each decision maker and an average efficiency (or fuel share) is computed for the sample. Instead of embedding this algorithm directly in the model, is there computationally faster approach to computing fuel shares and efficiency?

Table 5.6. Market Shares for Electric Heat (office building example)[a]

Electric Price	Gas Price (normalized to $/kWh) 0.02	0.04	0.06	0.08
0.04	100.00	100.00	100.00	100.00
0.05	100.00	100.00	100.00	100.00
0.06	100.00	100.00	100.00	100.00
0.07	98.00	100.00	100.00	100.00
0.08	91.00	100.00	100.00	100.00
0.09	75.00	99.00	100.00	100.00
0.10	64.00	92.00	100.00	100.00
0.11	56.00	77.00	100.00	100.00
0.12	49.00	66.00	94.00	100.00
0.13	43.00	56.00	79.00	100.00

(a) Decision criteria: four-year pay-back period.

In general, the principal alternative is to estimate a flexible function that relates efficiency or fuel share (separately or combined) to fuel prices. The parameters of this function would be empirically estimated from a single set of structured simulations (with a variety of fuel prices over a pre-defined range) using the Monte Carlo algorithm. This resulting function could be exploited to speed each year's solution of the forecasting model, in contrast to executing the full-blown Monte Carlo submodel.

The simplest approach is to combine the fuel choice and efficiency response into a single function for quantity of fuel, which takes the general form

$$Q_i/SF = f(P) \tag{5.2}$$

where Q_i/SF = energy type, i, per square foot of total floor space

P = vector of energy prices.

Note that the first term is not an EUI as typically defined, but rather is equivalent to an EUI multiplied by the fraction of total floor space served by fuel, k. The function, f, thus must reflect both the efficiency response and the fuel substitution response to changes in energy prices.

Because the function, f, must reflect both responses, it is difficult to develop the specific functional form from production theory. Although Jackson specified a Cobb-Douglas production function to generate the efficiency-cost frontier for a single fuel, the fuel substitution aspect was handled as a discrete choice. A more general approach would be develop a flexible production function for space conditioning that incorporated directly the relevant fuels, as well as the capital. This approach would simultaneously address efficiency (capital-fuel substitution) and fuel choice.

If we restrict this function to two fuels (electricity and gas) and capital, demand functions for electricity and gas can be represented as

$$Qe = g(Pk, Pe, Pg) \tag{5.3}$$

$$Qg = h(Pk, Pe, Pg) \tag{5.4}$$

where Qe, Qg = demand for electricity and gas (respectively)
Pk, Pe, Pg = prices of capital, electricity, and gas.

The form of these demand functions can be guided by recent developments in estimating flexible form production functions. The most common of these functions in the general economic literature is the translog production function, which can be considered an extension of the Cobb-Douglas function. The major difficulty in implementing these flexible forms is to ensure proper curvature conditions (i.e., substitution responses) for any arbitrary set of factor prices. This problem will be exacerbated in the case of fitting such functions to data generated by a limited set of technologies for specific buildings.

A second approach is to estimate a polynomial function (not necessarily derived from microeconomic production theory) that would provide a satisfactory response surface to the simulated fuel demands over a prescribed set of prices. In our application, note that this function would also incorporate the market response, as simulated through the Monte Carlo submodel, as opposed to the production frontier facing a single decision maker. One such function was estimated for the quantity of electricity from the simulations supporting Tables 5.3 and 5.4. The form of this function was

$$Q_e = b_0 + b_1 P_e + b_2 P_e^2 + \epsilon \tag{5.5}$$

In general, this function provided a very good fit to the data, with R^2 approximately 0.9 or higher. Several alternative ranges of gas prices were tested. The particular difficulty with this approach is that it sometimes failed to indicate diminishing returns for higher fuel prices. Moreover, it failed to capture the differential magnitudes of fuel substitution responses, as compared with efficiency (capital substitution) responses over particular ranges of electricity and gas prices.

As noted earlier in this section, the major purpose for estimating continuous functions is to eliminate the computational time required for the Monte Carlo submodel. Although developing flexible production functions to characterize the technology of commercial building space conditioning has an academic appeal, development for this reason alone should receive secondary priority.

A problem with the flexible forms in Equations (5.3) and (5.4) is that, ex post, one cannot differentiate between the efficiency and fuel choice responses. If that information is deemed important for policy analysis, functions would need to be estimated for these separate responses using data similar to that in Tables 5.1 and 5.2. Moreover, the

response functions described here are based upon a single-decision criterion (i.e., five-year pay-back).[a] In contrast, the Monte Carlo approach can provide a solution for any arbitrary set of fuel prices and decision criteria.

The decision to use the Monte Carlo approach across all time periods and building types for the model solution can therefore depend on whether its computational time can be kept within acceptable time limits. There is reason to believe that this may be possible. The discrete choice algorithm for a single representative building (or building type) can be completely described in terms of matrix routines in the GAUSS matrix language. In the simulations performed with the example data in the previous section, the time for a 100-firm sample was reduced to about 0.1 second on a 16-Mhz IBM personal computer system. Extrapolating to 250 representative buildings, the time requirement each year for this submodel would be about 25 seconds. On faster computers, the amount of time would be considerably less.

(a) In a general formulation, the pay-back criterion can be converted into a discount rate which, in turn, is a component of the rental rate or cost of capital. Thus, in terms of generating data to estimate the general functions, the price of capital and fuel prices would also need to be varied.

6.0 HVAC Characterization

To analyze energy use in the current and future stock of commercial buildings, adequate information is needed on the types of heating and cooling systems installed in these buildings. The wide diversity of loads within a large commercial building puts special demands on the HVAC equipment; this characteristic is normally not important for a residential structure. Since World War II, HVAC system designers have used many designs to improve comfort control in large commercial buildings within the constraints of system cost and maintenance requirements; however, energy consumption of these systems can vary widely. During the 1980s, HVAC system designers have been paying more attention to designs that address the issue of overall system efficiency.

This section outlines a proposed classification for HVAC systems to support an enhanced commercial sector model. This classification is needed for two reasons. First, to improve the energy efficiency of the existing stock of buildings, accurate information is needed on the characteristics of these buildings. In general, HVAC systems are not cost effective to change without complete renovation of the building. The types of existing systems will have an impact on other conservation measures that may be undertaken. For example, the energy impact of improved lighting efficiency will depend on the current HVAC system in the building. The classification is also necessary to provide a basis for projecting the energy requirements of future buildings. The two breakdowns of the CBECS buildings (existing and new) will be used in constructing representative buildings for the engineering simulation activities.

6.1 Classification of HVAC Systems

The information collected in the 1986 NBECS (EIA 1988) and 1989 CBECS (EIA 1991) dictates, to a large degree, the type of HVAC classification that is feasible for a general commercial energy forecasting model. Although the 1986 and 1989 buildings surveys from EIA have added substantially more information about HVAC systems than earlier NBECS, they have also dropped critical questions. To construct energy simulation models of CBECS buildings, additional information will be required.

A recent EPRI study separated central systems by four categories: 1) transport media, 2) delivery equipment, 3) duct system, and 4) air flow control (Pietsch 1988). Table 6.1 shows an estimated distribution of central systems in large office buildings, based on a very limited sample from the Building Owners and Managers Association.

Table 6.1. Estimated Distribution of HVAC Systems in Large Office Buildings

Central System Transport Media		Delivery Equipment	
All air	33%	Air handlers	64%
All water and Air/water	67%	Terminal units	36%
		Fan-coil	19%
		Induction	17%
Duct System		**Air Flow Control**	
Single duct	14%	Constant air volume	22%
Dual duct	19%	Variable air volume	42%
Multizone	31%		

Based on the above classification, the systems available in a simplified energy analysis method (ASEAM)[a] and information from the 1986 NBECS and 1989 CBECS, the following HVAC structure is proposed for the improved model. Three general types of systems are distinguished: 1) central, 2) zonal, and 3) no ventilation.

6.1.1 Central Systems

Central systems are defined as those systems that use HVAC equipment to serve more than one comfort zone of the building at a time. In very large buildings, more than one central system may exist; the key issue is that each of these systems serves multiple zones. The major reason for distinguishing central systems from zonal systems is that central systems often have to use offsetting heating and cooling air streams (reheating) to maintain acceptable comfort conditions in both interior and perimeter zones. Depending on the control system used, this approach can be very energy intensive, even though central systems often use large, efficient heating and cooling equipment (e.g., chillers and boilers).

Based on the above EPRI (Pietsch 1988) report classification, we further distinguish between central systems that use air handlers from those that do not.

(a) ASEAM is a engineering-based building energy simulation code (see Section 9.2.2).

6.1.1.1 Central Systems with Air Handlers

The following systems exist in the central systems using air handlers for distribution: 1) constant volume reheat, 2) dual duct or multizone, and 3) variable air volume (VAV) reheat. Each of these systems can be modeled in ASEAM.

In terms of the EPRI classification system, the reheat systems are synonymous with single duct systems. A single set of air ducts supplies cooling air to the various zones; the temperature of the cooling air is adjusted to match the zone with the highest cooling load. Because this temperature will be too low for other zones, the system is equipped with thermostatically controlled heating coils near each zone that are used to warm the centrally supplied air to the desired temperature. In older systems, the fan system operated at a constant speed to condition the building--therefore, the term "constant volume reheat."

Although the EPRI report (Pietsch 1988) differentiates the dual duct and multizone systems, these systems are quite similar in their operating characteristics. In these systems, central heating and cooling equipment may operate simultaneously.

The third major control strategy for an air distribution multiple zone system involves changing the volume of conditioned air to each zone by use of dampers or variable speed fans. Because some reheating may still be required, this system is termed a VAV reheat system.

6.1.1.2 Central Systems Without Air Handlers

Central systems that do not use air handlers generally use one of the following types of equipment located within the zone: 1) fan-coil units or 2) induction units. The fan-coil units appear to be slightly more prevalent. A fan-coil unit includes a blower and a heat exchanger located in a building comfort zone. The blower circulates air over the heat exchanger, and the air is supplied by heated or chilled water from a central plant.

Fan-coil units generally have two or four pipes. The simpler two-pipe systems are in either a heating or cooling mode. Winter seasonal changeover from central chilled water to heated water is required. Four-pipe systems can supply both heating and cooling simultaneously. In four-pipe systems, no reheating is required. The zone is either receiving cooled or heated conditioned air.

An induction unit is located in the building comfort zone and is supplied with conditioned air, normally at high pressure. It does not have an attached blower; the velocity of the centrally supplied air is sufficient to cause mixing with the zone's air. The units incorporate a thermostatically controlled damper mechanism that regulates the amount of

conditioned air entering the zone. The high-velocity, high-pressure duct systems that are normally used with these units require more fan power than the systems using air handlers (see Section 6.1.1.1). On the other hand, these duct systems can use smaller ducts.

6.1.2 Zonal Systems

Zonal systems have dedicated HVAC equipment for each zone of the building. For our classification, this HVAC equipment also provides some type of forced air ventilation. These systems are often referred to as package systems because the generally smaller capacity equipment comes from the manufacturer assembled as a package. An example of a zonal system would be a one-story retail or office building using multiple heat pumps for both heating and cooling. In very small buildings (e.g., residential size) what may casually be termed as a central system is, in our classification, a zonal system. The entire structure is treated as one zone with one thermostat to control the temperature.

Zonal systems usually maintain comfort conditions in the zone by providing a constant volume of air at temperatures that vary according to the load. This system is also often termed a constant volume single zone system or a variable temperature single zone system.

6.1.3 No-Ventilation Systems

The no-ventilation systems are similar to zonal systems, with the exception that they do not to distribute conditioned air to the various zones. Instead, the no-ventilation systems rely on operable windows and infiltration for ventilation.

These systems use a variety of heating and cooling equipment. For heating, electric resistance baseboards make up the majority of non-ducted heating equipment in commercial buildings. Older buildings that have steam radiators for heating also fall into this category.

Air conditioning equipment consists of either room air conditioners or packaged terminal units. Room air conditioners are mounted in windows or through-the-wall sleeves in each zone, and package terminal units are mounted in through-the-wall sleeves in each zone. Both types of units can optionally generate heat by means of hydronic coils or electric heaters located inside the unit.

6.2 System Information in the NBECS/CBECS

The information in the 1986 NBECS (EIA 1988) and 1989 CBECS (EIA 1991) provides at least a partial basis for identifying many of the above categories. The presence of a chiller would generally indicate a central system. Information on fan-coil units is provided, but specific information is not provided on induction units. There are significant system efficiency differences between the various combinations of duct systems and air-flow control mechanisms. For buildings with central HVAC systems, we need to make assumptions about the duct system, as shown in the previous section. The question about VAV was in the 1986 NBECS, but it was dropped in the 1989 survey.

The questions related to heating and cooling systems have changed considerably from the NBECS from 1979, 1983, and 1986 (EIA 1981, 1985, and 1988) to the subsequent 1989 CBECS (EIA 1991). Gradually, EIA has requested more information related to specific equipment in the building but has dropped more vaguely worded questions about system type. The progression of questions with respect to central cooling systems illustrates this point.

6.2.1 1979 NBECS

The 1979 NBECS (EIA 1981) asked one question about the cooling system in the building (Question 54).

> What kind of cooling system or systems supply the air conditioning for this building? Please look at this card and pick the <u>ONE</u> choice that most nearly describes the air conditioning system here.
>
> a) Window units only.
> b) One or more packaged units (i.e., built and assembled at a factory and installed as a unit at the building) that cool all, or portions, of this building.
> c) A single central system which serves all areas of the building that are air conditioned and was specially constructed for this building.
> d) Something else or any combination of the above.

6.2.2 1983 NBECS

For the 1983 NBECS, an additional category for wall units was added, and the term "packaged" was dropped (EIA 1985). The two relevant questions from the 1983 survey (Questions 38 and 39) were as follows:

> "Is any of the air conditioning in the building supplied by: 1) window units, 2) wall units, and 3) central system? (Question 38)

"There are two types of central systems. The first type of central system is built for use in many buildings, while the second is designed and especially built for a particular building. Which type of central system is in use in this building?" (Question 39)

6.2.3 1986 NBECS

In the 1986 NBECS the question related to central cooling was embedded in a list of specific types of HVAC equipment (EIA 1988). A subsequent question sought information on the distribution system (Question E-3).

During the 1986 calendar year did this building use:

a) Boilers inside the building
b) Furnaces that heat air directly
c) Water source heat pump
d) Air source heat pump
e) Central cooling (for example, chillers)
f) Electric baseboards, individual space heaters, free standing or mounted in walls or floors
g) Individual air conditioners, mounted through the walls or windows
h) Packaged rooftop units used for heating
i) Packaged rooftop units used for cooling
j) Evaporative cooler
k) Some other heating or cooling equipment.

6.2.4 1989 CBECS

In the most recent CBECS, the term "central cooling" was dropped entirely (EIA 1991). The questions on equipment and distribution were combined. The list related to cooling (Question D-10) was as follows:

"Here is a card showing different types of equipment that may be part of the building's cooling system. During the past 12 months, did this building use any:

a) Central chillers inside the building that chill water for air conditioning
b) Individual room air conditioners mounted in a window or wall
c) Packaged air conditioning units, usually mounted on the roof or on a slab beside the building
d) Heat pump
e) Air ducts or air handling units
f) Circulating chilled water with fans
g) Any other equipment for cooling.

The effect of these changing definitions is shown in Table 6.2.

6.3 Results of NBECS/CBECS Surveys

It is not clear why the number of reported central systems declined between the 1979 and 1983 surveys (EIA 1981, 1985). In 1986, the number of central system increases occurred primarily because the major alternative (package systems) was restricted to roof-top units (EIA 1988). In the 1989 survey, that problem was rectified, but the choice of only a central chiller precludes the identification of air (DX) cooling units that may serve in a central system of a medium-size building (EIA 1991).

Even the 1979 and 1983 NBECS (EIA 1981,1985) cannot provide consistency with our concept of a central system that simultaneously serves multiple zones. More than one-half of the central systems in the 1979 survey are reported to be in buildings of less than 5000 square feet. It is likely that most of these buildings would act as a zonal (single zone) system. To conclude this example, the number of central systems is likely greater than the number of central chillers (200,000 buildings), but smaller than the number of reported central systems (560,000 buildings) in the 1983 NBECS (EIA 1985).

Table 6.2. Distribution of Cooling Systems and Equipment in Various NBECS and CBECS[a]

			Number of Buildings, thousands				
Year	Total	Cooled	Central	Packaged	Window	Wall	Other
1979	4238	1530	769	800	856	N/A	302
1983	3948	2643	564	1184	812	406	314
1986	4154	2906	1111	730	1074		334
1989	4528	3184	201[b]	1980	1074		437

(a) Data from NBECS and CBECS are from the following sources: Table 18a, NBECS: Building Characteristics (EIA 1981); Table 33, *NBECS, Characteristics of Commercial Buildings 1983* (EIA 1985); Table 49, *NBECS, Characteristics of Commercial Buildings 1986* (EIA 1988); Table 86, *CBECS, Commercial Buildings Characteristics 1989* (EIA 1991).

(b) Central chiller only.

This example should clarify why considerable judgment will need to be applied to develop representative buildings with HVAC systems that statistically represent the commercial building population. Building size and age will have to be considered, as well as the reported HVAC characteristics, in order to assign the most probable system in a building simulation methodology.

7.0 Lighting and Other End Uses

This section proposes a general approach to modeling lighting and other end uses in a revised commercial sector model. Lighting is very important in the commercial sector, accounting for approximately 25% of total (primary) energy use. The other end uses are refrigeration, cooking, hot water, office equipment, and miscellaneous uses.

7.1 Lighting

Lighting efficiency is handled in various ways in the existing commercial models. In CEDMS, Jackson incorporates a discrete choice methodology similar to the HVAC approach discussed in Section 6.0. COMMEND incorporates price elasticities. In the PNL model, lighting efficiency was specified as an exogenous time trend.

For the enhanced model, we propose an expanded version of the approach used in CEDMS. This approach requires a database on the efficiencies and costs of various lighting technologies; fortunately, a suitable database for this purpose has already been developed. In support of the FEMP, PNL has created the lighting technology screening matrix (LTSM).[a] The LTSM contains technical and cost information for several hundred different types of fluorescent and incandescent lighting.

The LTSM contains cost information broken out by the bulk (total) fixture and for different components (e.g., ballast, tubes, or reflectors). This detail is important depending upon whether the lighting choice applies to a new building or to a retrofit. For retrofit, ballasts or tubes or both can be changed without changing the fixture. The LTSM also contains information on the labor requirements of specific retrofits. Thus, the cost estimates can be regionalized depending upon prevailing wage rates.

7.1.1 Interactions with Heating and Cooling

One of the key issues related to the treatment of lighting is its interaction with HVAC energy use. Greater lighting efficiency reduces interior heat loads. This leads to lower cooling energy use but higher heating use. The extent of these interactions depends upon the HVAC system, the operating schedule, and the physical characteristics of the building.

(a) The *Lighting Technology Screening Matrix User's Guide* is a package that can be obtained from Charles Purcell, Battelle Washington Office, 901 D Street SW, Washington, D.C. 20024-2115 (phone [202] 646-5206).

The most recent COMMEND model treats these interactions via what are termed as "heating interaction parameters and cooling interaction parameters." The heating interaction parameter for lighting defines the amount of annual lighting energy that ends up as an internal gain during the heating season, thus reducing heating loads. The "cooling interaction parameter" is defined in the opposite manner except that the internal gain augments the cooling load. The offset amounts (in Btu) are divided by the heating or cooling equipment efficiency to determine the change in energy use. From the available information, it is not clear how these interactions are handled in CEDMS. An interaction is not considered in the PNL commercial model.

The use of the interaction parameters in COMMEND maintains an independent optimization submodel for lighting. Within the lighting discrete choice framework, the cooling benefits and heating disbenefits of more efficient lights can be included explicitly. Operationally, the optimal lighting technology would be determined outside of the engineering simulation model.

An alternative approach is to include various lighting technologies in conjunction with the HVAC choice algorithm. For example, one or more lighting technologies might be associated with each of the options in Table 5.1. The technology choice methodology would, thus, be expanded to consider various bundles of building equipment (both HVAC and lighting). The energy use of these bundles would be determined within the engineering simulation model. The heating and cooling interactions would be incorporated explicitly in the building energy use estimates.

Although this alternative approach has a conceptual elegance in that lighting and HVAC choices are explicitly linked, we propose that the COMMEND approach be followed in the revised model. The use of the somewhat ad hoc interaction parameters has several advantages. First, it likely reduces the number of separate technology sets that need to be evaluated in the forecasting model. Not only do we need to consider various HVAC characterizations with different lighting configurations, but also those characterizations with various operating schedules. Secondly, it allows independent evaluation of programs or technologies that are devoted strictly to lighting. Finally, it makes the accounting of the stock of various lighting technologies easier within the model.

The heating and cooling interaction parameters would be derived for each building prototype. Thus, the engineering simulation model would be run for various lighting intensities and operating schedules to determine the interaction effects. Depending upon the results of this task, a regression model could be constructed to project the interaction parameters for various combinations of equipment.

7.1.2 Interior and Exterior Lighting

The most recent COMMEND model disaggregates lighting into interior and exterior lighting. Based upon the End-Use Load and Consumer Assessment Program (ELCAP) sample of buildings in the Northwest, exterior lighting can range from 10% to 25% of total lighting requirements in certain categories of commercial buildings.

Disaggregating lighting into interior and exterior lighting leads to more realistic technology choice models for each. High-intensity discharge lamps are primarily used for exterior lighting. These lamps can be compared with standard incandescent and advanced incandescent lamps.

7.2 Other End Uses

Other end uses (e.g., refrigeration, cooking, hot water, office equipment, etc.) are estimated to account for between 20% and 25% of total primary energy use in the sector. The end uses have generally received little attention in existing commercial energy models.

One reason for the lack of attention to these end uses is that most end uses do not apply to every building type. For example, cooking is concentrated in restaurants; office equipment is primarily found in office buildings; and refrigeration is primarily found in grocery stores and some warehouses.

Credible data related to these end uses are lacking. For instance, there is wide perception that the growth of office automation (i.e., office equipment and personal computers) is a key element behind high rates of growth of electricity use in the commercial sector. Unfortunately, there is little empirical information that can lead to strong quantitative statements as to actual impact from this source.

For most of these end uses, the convention of normalizing consumption to square footage is not the best way to characterize these uses. For example, cooking energy use per square foot would widely vary between full- and fast-service restaurants. If data were available, a better normalization might be the number of customers served.

7.2.1 Why Analyze Other End Uses?

Given that the total of these other diverse end uses may only comprise about a quarter of the commercial sector energy use, a reasonable question is how much attention should be devoted to this topic? From an energy modeling and forecasting standpoint, the following discusses three reasons to pay attention to these end uses.

1. From an engineering perspective at the individual building level, there are interactions between many of these end uses and the space conditioning loads. Cooking, office equipment, and refrigeration (in some cases) generate internal heat gains that must be handled by the building's cooling system.

2. Increasing penetration and intensity of these end use may significantly influence overall trends in energy consumption in the sector. As mentioned above, this is widely perceived to be the case with respect with office equipment and personal computers. Cooking energy use in the commercial sector will continue to increase as consumers eat a greater percentage of meals outside the home.

3. These end uses may present some significant energy conservation opportunities in their own right. Some office and computer equipment manufacturers have begun to promote equipment that draws less power in a "standby" mode. Improved tank designs, insulation materials, and recovery of waste heat are all technologies to reduce hot water energy use. The technologies used for refrigeration are obviously closely related to those used for space cooling equipment.

The same discrete choice modeling framework could be applied to these end uses, as has been previously argued for HVAC and lighting. From a practical standpoint, however, the availability of suitable cost and performance data for commercial equipment serving these end uses is very limited. A major effort to collect such data and modify the model framework to include a decision-making algorithm is not likely to significantly enhance the model's overall energy forecasting and policy evaluation capability.

Reasons one and two above provide sufficient grounds to improve our basic knowledge of the relative importance of these end uses by building type. A better understanding of the magnitude of the internal heat gains associated with this equipment can improve the accuracy of engineering simulation work analyzing different envelope and equipment technologies. Understanding key trends in these end uses will benefit historical calibration exercises.

7.2.2 Recent and Ongoing Data Collection Efforts

There are few existing estimates of energy use for miscellaneous equipment (i.e., outside of HVAC and lighting) in commercial buildings. The EUI estimates for these end uses in the existing end-use models are not well documented. A portion of the intensity estimates are presumably based upon the engineering assumptions (default values) that are used in building energy simulation models such as DOE-2. Thus, for water heating, the EUI can likely be traced to assumptions regarding the number of gallons of hot water required per building occupant. For PNL's commercial sector model, cooking EUIs were based upon a small sample of seven restaurants that were metered in the early 1980s.

Several recent research efforts have the likelihood to markedly improve the characterization and measurement of these miscellaneous equipment loads. The first involves the end-use metering project in the Pacific Northwest that has been conducted by the Bonneville Power Administration. The second project is a study of non-HVAC and lighting loads in the commercial by Arthur D. Little, Inc. (ADL) for OBT. These two projects are discusses briefly in the following sections.

7.2.2.1 Pacific Northwest Metering Study

The Bonneville Power Administration began metering commercial through ELCAP in 1986. Under ELCAP, PNL has collected and analyzed end-use data, as well as information on occupant and structure characteristics, for a sample of 126 commercial buildings. In 1990, PNL published *Commercial Equipment Loads, End-Use Load and Consumer Assessment Program*, a study that analyzed hourly electric loads for seventeen classes of equipment (Pratt et al. 1990).

The methodology behind the PNL study was intended to permit as wide of a generalization as possible about these loads, beyond the sample of buildings that were actually metered. The first step in the methodology was to measure the capacity density of the equipment population. The capacity density is the number of kilowatts per square foot of building floor area. The capacity density estimates are based upon counts of individual equipment and name-plate rating information that were collected at the time meters were installed in the buildings.

The second step in the methodology involved the development of utilization factors for each class of equipment. Utilization factors account for a device's average operating time (the fraction of total hours in the year that the equipment operates) and its average load factor (the fraction of the equipment's name-plate rating that is actually drawn when operating). In many cases, different types of equipment are metered together (e.g., task lighting, personal computers, and office equipment). In such cases, a regression (conditional demand type) model was used to infer the utilization rates for specific types of equipment.

The final step was to estimate consumption by equipment type and building type. The consumption estimates are simply the products of the capacity density and utilization rate. Table 7.1 shows the consumption estimates rolled up to a Pacific Northwest total; consumption is expressed in terms of average megawatts.[a]

(a) The eight end-use categories shown in Table 7.1 were collapsed from a more detailed 17-category listing shown in the PNL report (Pratt et al. 1990). The building categories are also collapsed.

Table 7.1. Estimated Loads in the Pacific Northwest by Building Type for Eight Equipment Categories (in average MW)

	Office	Retail	Restaurant	Grocery	Warehouse	Other	Total
Office Equipment	30.4	18.9	2.1	1.8	7.8	16.3	77.3
Personal Computer	28.1	13.0	0.7	0.8	0.8	5.9	49.5
Large Computer	62.6	0.6	0.0	0.0	0.0	0.2	63.5
Task Lighting	3.0	11.5	1.2	0.9	0.1	17.6	34.2
Food Preparation	5.6	11.6	62.1	20.2	1.7	9.4	110.7
Refrigeration	12.5	34.0	79.6	206.1	5.8	44.1	382.0
Hot Water	7.2	4.8	25.2	9.1	0.5	167.4	214.1
Other	31.7	13.8	36.0	22.5	6.1	65.0	175.0
Total	181.1	108.2	206.9	261.3	22.9	325.8	1106.2

Table 7.2 shows a percentage breakdown of these equipment loads by building type. When looking at the relative magnitudes of the loads, keep in mind that the categories exclude natural gas. A few of the buildings used natural gas for water heat, which would increase the relative share of that end use. The large number of the total loads accounted for by water heating in the "other" building category is the result of motels and schools included in the category.

The tables clearly show that refrigeration accounts for perhaps as much as one-third of the other end uses. Refrigeration is the dominant miscellaneous equipment use in grocery stores, but it also accounts for a major fraction of these loads in retail, restaurant, and warehouse buildings.

Although the increasing penetration of PCs has received the most public attention for load growth implications, the estimates in Table 7.1 suggest that mainframe computers were still the largest energy user in the region as of 1989. Note that office equipment in general is also estimated to account for 50% more electricity use than PCs.

Table 7.2. Percentage Breakdown of Loads in the Pacific Northwest by Building Type for Eight Equipment Categories

	Office	Retail	Restaurant	Grocery	Warehouse	Other	Total
Office Equipment	16.8	17.4	1.0	0.7	34.3	5.0	7.0%
Personal Computer	15.5	12.0	0.4	0.3	3.7	1.8	4.5%
Large Computer	34.6	0.6	0.0	0.0	0.1	0.1	5.7%
Task Lighting	1.7	10.6	0.6	0.3	0.5	5.4	3.1%
Food Preparation	3.1	10.7	30.0	7.7	7.6	2.9	10.0%
Refrigeration	6.9	31.4	38.5	78.9	25.2	13.5	34.5%
Hot Water	4.0	4.4	12.2	3.5	2.1	51.4	19.4%
Other	17.5	12.7	17.4	8.6	26.5	19.9	15.8%
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0%

7.2.2.2 A. D. Little, Inc., End-Use Study

ADL is an engineering consulting firm currently undertaking a study for OBT to characterize non-HVAC and lighting end uses in the commercial sector.[a] The ADL study is looking at office equipment, water heaters, refrigeration, cooking, vending machines, and water coolers. The primary emphasis of the study is to generate national energy consumption estimates of these end uses by building type. DOE intends to use the information as a basis for technology evaluation and policy formation.

A secondary emphasis of the study is to estimate the technical potential energy savings for each of these end uses. ADL is enumerating and describing various technical options that can reduce energy consumption for these types of equipment. The study will not specifically address the probable costs of these technologies; that area can be addressed in potential future case studies.

(a) The report, currently in draft form, is entitled *Characterization of Commercial Building End-Uses Other Than HVAC and Lighting.* ADL is performing this work for the Office of Building Energy Research, a division of the OBT.

The ADL study is currently in draft form and not expected to be finalized until early 1993. Although we cannot cite quantitative results in this report, we can describe the approach ADL is using to develop end-use consumption estimates. In general, the ADL approach is similar to PNL's Northwest study. The first step is to develop current population estimates for each category of equipment. ADL constructs national estimates of equipment stocks in place on the basis of historical sales information and estimated retirements. These stocks of equipment are allocated to particular building types on the basis of available survey information and expert judgment. Compared with the PNL study, ADL is also looking at gas equipment for water heating and cooking.

The second step in ADL's approach involves estimating the annual energy consumption per unit of equipment. This requires estimates of the equipment's average rated capacity in the current stock. These estimates are built up from efficiency estimates of each historical vintage of equipment. Utilization factors are then applied to the rated capacity to generate average consumption per hour that the equipment is turned on. The utilization factors incorporate both percentage of peak capacity and energy used during standby mode. Finally, an estimate of the typical operating hours for each type of equipment in each building category is constructed.

To develop the information in the second step, ADL has consulted a variety of sources, including manufacturers, product literature, and utilities. For some products, the utilization factors and operating hour information from the 1990 PNL study were used.

The ADL study will be a valuable resource to fill in much of the missing information in our existing knowledge about the relative importance of these other end uses at the national level. Future commercial modeling activities should be able to incorporate the forthcoming ADL results to provide national control totals for these end uses.

8.0 Choice of Prototypical Buildings

The selection of representative or prototypical buildings is a major step in the overall commercial energy forecasting model development. These buildings are used in the building simulation tool as a basis for estimating the energy use of various technologies. The results of these simulations are then passed to the technology choice submodels within the general forecasting model.

The nation's stock of commercial buildings is highly diverse. Buildings range from small wood-frame structures to large steel and glass tower structures. The climate diversity in the United States also leads to some buildings with no cooling loads, while other buildings require no heating. Differences in energy use per square foot can be more than an order of magnitude.

This first part of this section discusses general issues related to structuring a set of prototypical or representative buildings. The second part of the section covers alternative methods to developing specifications for such buildings. The final section briefly describes some prototypical buildings that have been used to support several existing commercial energy models and standards development projects.

8.1 General Issues

The diversity of the commercial building stock generally suggests that a large number of building categories will be required to accurately portray how the sector uses energy. Whenever a representative building is used to model the energy use of a building category, the user, in effect, assumes that all of the buildings within that category behave as the representative building. To the extent that the buildings in the category differ from the representative building, error results. The size of this error may be sufficient to bias an evaluation of a potential new technology. If too few categories are defined, technologies may well be cost effective or technically feasible for a significant fraction of buildings within a given category without being so for the representative building.

In 1986, PNL undertook a project for the Gas Research Institute (GRI) to address this issue. The objective of the project was to develop a small number of representative buildings for the U.S. office building sector. The GRI was facing a dilemma between accuracy and expense in evaluating its projects to develop new gas-fired HVAC equipment. The diversity of office buildings suggested that energy simulations be performed on a large number of representative buildings to maintain a reasonable level of accuracy. On the other hand, the labor and computer expense of many simulations, sometimes reaching into the hundreds, was deemed to be unacceptable.

The PNL study recognized the tradeoff between accuracy and expense as leading to the view that the representative buildings are a scarce resource. Such a resource needs to allocated very carefully. Creating categories for small groups of unusual buildings would not be cost effective.

The approach used by PNL in the GRI study will be described in a following section (see Section 8.2). The main point in this study is that the same cost/accuracy issue faces the users of the improved commercial sector model. In spite of the advances in computer technology, building energy simulation models are voracious users of computer resources; even more compact energy simulation models require minutes of computer time on today's fastest microcomputers. With perhaps several hundred prototypical buildings to cover the entire commercial sector, the total time required by the engineering simulation model will require several hours. This requirement may not be restrictive if the simulation model needs to be run occasionally. The major difficulty may involve the forecasting model where implementing the simple technology choice algorithm (see Section 3.0) for many prototypical buildings could cause the entire model to run for an unacceptably long period of time.

To further complicate matters, the choice of prototype buildings is not unrelated to what the model might be asked to evaluate. A simple case might be the introduction of an improved lighting technology. In this case, the most accurate categorization of the building stock might be strongly based on weekly operating hours. Those buildings with longer operating hours might be the first to adopt a more efficient technology that may also be more costly. On the other hand, a new heating technology would need to be evaluated across a finer division of climate zones.

8.1.1 How Many Prototypes?

Although there is the strong intuitive notion that more prototypes will reduce error, we need to face the issue of how many prototypes are enough. The aggregation error of using only a small sample to represent the entire population comes about from basically two sources: 1) nonlinearities in physical processes and 2) the discrete nature of technology choice. The first source can be represented by a mathematical inequality, considering energy use as a function of building attributes:

$$\overline{f(X)} \neq f(\overline{X}) \tag{8.1}$$

where X = vector of physical building attributes
$f(X)$ = energy use.

The mean of X, of course, can be considered a conventional way of representing a prototype building. For commercial buildings, nonlinearities stem from several sources, principally stemming from building geometry and thermal mass effects.

The discrete, mutually exclusive nature of many technologies also contributes to aggregation error within a model. Many examples could be cited. For instance, only large buildings can economically use central chillers. A specific switch-over point in terms of building size exists (given efficiencies and cost), beyond which chillers are the preferred alternative; otherwise a package system is chosen. Mathematically speaking, this manifests as a discontinuity in the function that maps physical characteristics information into energy consumption.

Another example relates to operating schedule and lighting. At a given cost, adopting a more efficient technology is the preferred option only for buildings that operate more than a certain number of hours per week. Consider a population distribution of buildings by weekly operating as shown in Figure 8.1. By some method, we assume that we have developed prototype buildings with two types of operating schedules, at points A and B. Each is assumed to represent half of the building stock. At cost point 1, only buildings with weekly hours greater than S1 would employ the more efficient technology (e.g., ballast). Because prototype B falls into this group, the model analysis would show it adopting this analysis. Thus, for this simple example, a model-based result would be a market penetration of 50% with this technology.

With the same example, let us next consider a building with weekly hours at point S2. Although prototype A is close to S2, a pure discrete choice algorithm would find it choosing the conventional technology. The model would still show 50% market penetration by

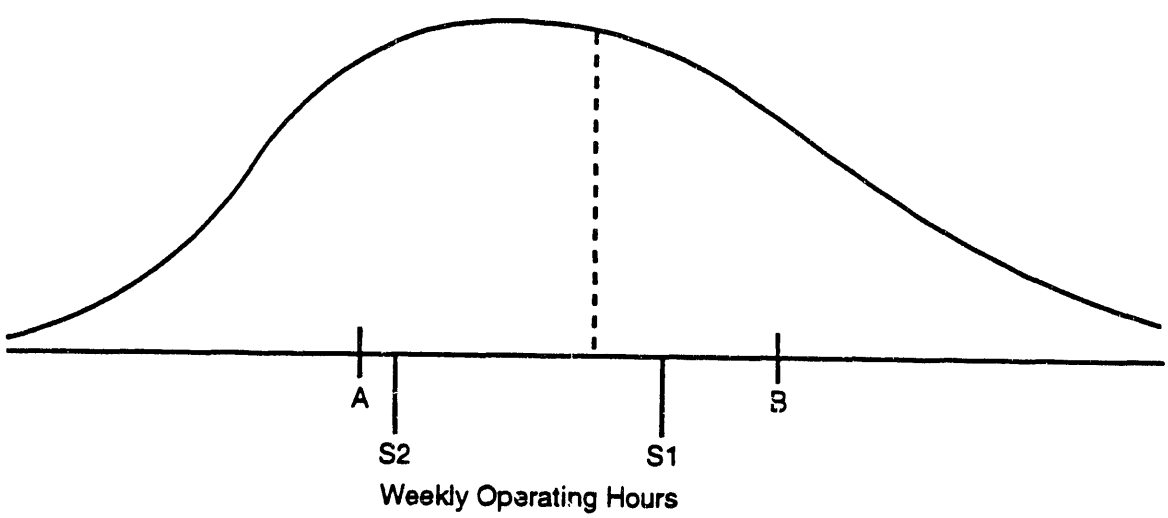

Figure 8.1. Market Penetration With Two Prototype Buildings

the efficient technology. If A and B are the means of their respective halves of the distribution, then the market penetration error for the more efficient technology could range up to 25 percentage points. At cost point 2, generating a lower payback for the efficient technology for weekly hours at S2, the use of the entire distribution would indicate approximately a 75% market penetration for the efficient technology. By collapsing the distribution to two single prototypes, the same critical cost point yields only a 50% penetration.

This example suggests a way to bound the error in generating market penetrations. Consider the same distribution in Figure 8.2. In this example, we divide the total market along the continuum of weekly hours into five equal segments, indicated by the dashed vertical lines. The prototypical buildings are defined to match the means of each segment and are represented by points A through E. From the discussion in the preceding paragraph, it is clear that regardless of what the critical number of weekly hours are to determine a technology change, the error in the market penetration will be less than 10%. If the critical number of weekly hours is at point S1, the model will indicate that three prototypes will adopt the technology (60%), whereas the true percentage would be closer to 70%. At point S2, the model indicates a penetration of 80%, as compared with the true value of near 70%. As we approach points such as S3, the error tends to zero, with both results at 80%.

In this simple case, with one classifying variable (weekly hours) we can posit that market distribution error can be held to less than x percentage points, as long as we have a minimum of x/2 prototypes, each representing no more than 2x percent of entire distribution. In this case, the rule is simple because the classifying variable maps directly into

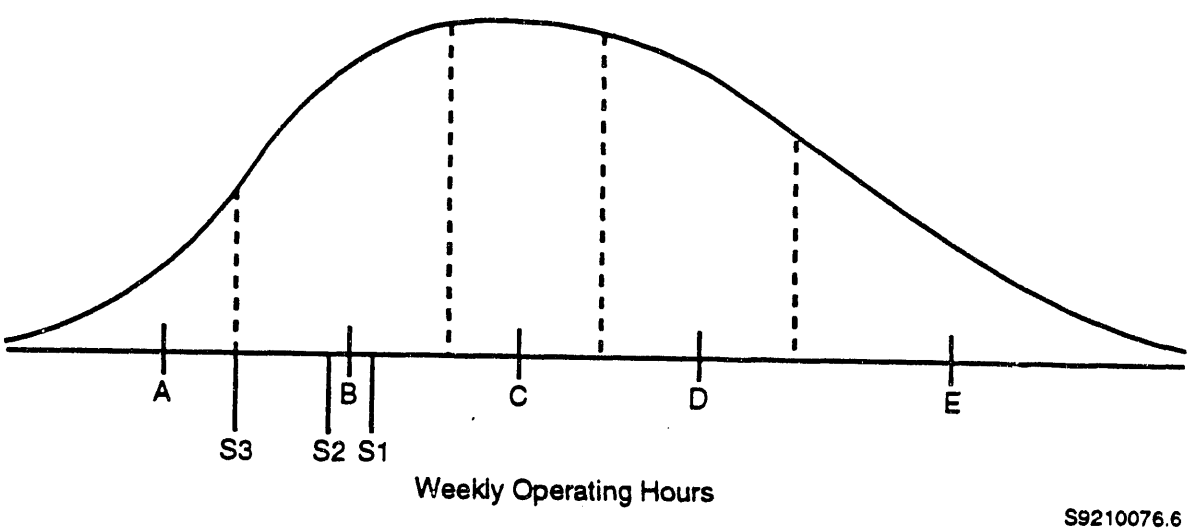

Figure 8.2. Market Penetration With Five Prototype Buildings

energy use. We may want prototype buildings to integrate both physical and energy characteristics. This will lead, in some cases, to the dissimilar buildings--with different prototypes--having the same energy use characteristics. Thus, the number of prototypes with the similar energy use characteristics may be greater than the 2x percent rule cited above. In this situation, we have to interpret the rule above as a necessary condition to achieve a given error bound, but it may not be a sufficient condition.

Finally, note the aggregation error discussed above relates to the market penetration algorithm and not to energy intensities or consumption per se. We could use a single prototype with the overall average weekly hours if we were only interested in the energy impact of introducing the more efficient technology to the entire stock. The question of whether more than one prototype is required for energy consumption analysis then depends upon the degree of nonlinearities, as mentioned at beginning of this section (see Equation [8.1]).

8.1.2 Energy Characteristics Versus Physical Characteristics

As a general statement, the categorization of buildings need only be concerned with how buildings use energy. Buildings that use energy with different intensities, for different purposes, or on differing schedules should be listed in different categories.

Most previous studies and modeling efforts have used physical characteristics (e.g., size, climate, and HVAC system) to define building categories. The use of physical characteristics can lead to prototype buildings that may show little change across one or more characteristic dimensions. An example may be large office buildings whose energy intensities may be relatively insensitive to climate differences. If each prototype building is viewed as a scarce resource, this emphasis on climate as a basis for categorization may not be optimal.

The opposite approach is to define building categories solely on how they use energy. This approach, however, can lead to categories that have very different physical characteristics grouped in the same category. For example, a small wood-frame building in the South may have the same energy intensity as a mid-size, multi-story building in the Northeast. Even with similar energy use patterns, the choice of certain types of HVAC equipment may be different for these two buildings (e.g., roof-top heat pumps). This logic suggests that both energy use and physical characteristics should be considered in a general categorization scheme.

8.2 Methods to Define Prototypical Buildings from Sample Data

The issues discussed in the previous section imply that we need to develop original prototypical buildings from available survey information for the improved commercial model. Although this is a preferred course of action, an alternative approach is to use prototypes that have been developed previously for national or regional energy studies. In the following section, we review prototypes that have been used in several of these types of studies.[a]

8.2.1 Traditional Matrix Approach

The traditional approach to categorizing buildings is to define a matrix of characteristics, such as size and climate. This approach is feasible when the number of characteristics is small. For example, three size classes (small, medium, and large) and five climates zones lead to fifteen categories. From these categories evolve the prototypical buildings with specific assumptions about size and climate. These parameters are determined on either a statistical or judgmental basis to best represent each of the categories.

This approach runs squarely into the accuracy-expense tradeoff as more characteristics are considered. Operating schedule is extremely important from the point of lighting requirements. Age is often a good proxy for HVAC system type and envelope thermal characteristics. A modest expansion of the traditional matrix approach might use two operating schedules and three age classes (pre-war, post-war, pre-embargo, and post-embargo). The matrix approach now yields a total of 90 categories. A breakout of other key structural parameters would further increase the number of categories. Clearly, the traditional matrix approach can lead to large number of categories, with the possibility that many of the categories may be statistically insignificant.

8.2.2 Cluster Analysis

The approach used by PNL in the study for GRI (Briggs et al. 1987) used cluster analysis with the 1979 NBECS data set (EIA 1981). Cluster analysis is a statistical procedure that groups observations of a data set with similar characteristics. Operationally, the categories are defined as the groups of observations in the data set rather than through the n-dimensional boundaries of the matrix approach. Cluster analysis differs from the matrix approach in that it views the resulting clusters as clouds of observations rather than as cubes in space. Figure 8.3, taken from the PNL report (Briggs et al. 1987), illustrates this point, with two hypothetical characteristics.

(a) The first part of the following discussion borrows heavily from the 1987 PNL report for GRI that developed a categorization for office buildings (Briggs et al. 1987).

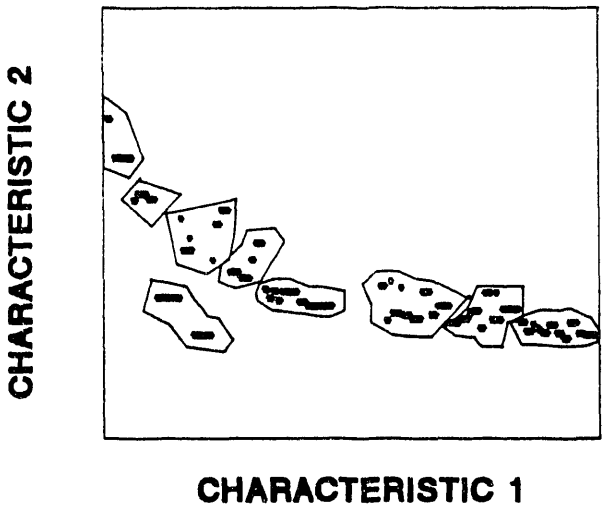

Figure 8.3. Cluster-Based Categories

In Figure 8.3, the categories can overlap in one or more dimensions. Each observation belongs to a cluster. For each cluster, a prototype can be defined in various ways, but normally is based on the mean value for each of the dimensions. The mapping of observations on the prototype defines the category rather than the ranges of the key parameters. The statistical weight of the prototype is defined as the sum of the weights of the individual observations in the cluster.

Cluster analysis works by developing a distance metric between each pair of observations. The metric is normally a Euclidean measure that is calculated from the values of each of the characteristics. Observations that are close together are grouped within the same cluster. Outliers in the data set are often assigned their own clusters (at least initially). A large number of algorithms are available to perform cluster analysis. The algorithm used in the PNL study was part of the statistical analysis software (SAS) package (SAS Institute 1985).

The office categorization study used both physical characteristics and estimated end-use loads in the cluster analysis. The estimated end-use loads are not available in building survey data such as NBECS. To generate these loads, a simplified energy model was simulated for each of the 1139 office buildings in the 1979 NBECS (EIA 1981). This effort involved using available weather and building characteristics data in the NBECS along with professional judgment to determine parameters for the energy simulations. Total energy use by building from the NBECS was used to calibrate general parameters within the simplified model.

After the simplified energy model had been calibrated, it generated the following annual loads for the NBECS buildings:

- cooling coil
- heat addition
- reheat coil
- supply fan
- lighting
- receptacle and elevator.

In addition to these estimated loads, the following physical characteristics were used in the cluster analysis:

- building floor area
- number of floors
- year built
- climate/census region
- heating degree days
- cooling degree days.

The cluster analysis generated 20 clusters, with the restriction that the smallest cluster contain at least 1.5% of the total office floor area. The prototype buildings were then based on the mean values of the variables shown above. These variables, along with other inputs developed primarily from professional judgment, were used to construct DOE-2 input files for each of the 20 building categories.

In general, the cluster analysis approach has some important advantages over the traditional matrix approach. The resulting categories were linked to the underlying data set on a rigorous statistical basis. The process was basically objective, with few assumptions about what was typical or customary in building construction. The process was able to blend information on physical characteristics as well as energy use to generate a manageable number of categories.

On the other hand, the cluster analysis approach does have some drawbacks. Although the categories are, in general, tighter than they would be under a matrix-based approach, the resulting categories are difficult to characterize in a simple manner. This makes the acceptance of such categories more difficult across a wide range of users. Also, the linkage to the database is most relevant if we are using the model to analyze the existing stock (i.e., sample) of buildings. Defining clusters for new buildings is more problematic.

Finally, using a distance metric presents problems for certain characteristics of buildings. The difference between a nine-story and ten-story building is much less than between a one-story and two-story building, given the type of equipment than can be used in one-story versus multi-story buildings. Distinguishing between one-story and multi-story buildings is not an option; cluster analysis cannot really handle categorical variables.

8.2.3 Modified Matrix Approach

Although the cluster analysis approach yields a manageable number of categories, we can speculate whether some alternative approach might overcome some of its drawbacks discussed above. Essentially, can we use concepts from both approaches to generate a small number of categories that can be easily interpreted in terms of physical characteristics of the buildings?

The outline of a procedure that we might term as a modified matrix approach to categorization can be found in next paragraph. The essence of the procedure is straightforward. First, we perform a traditional matrix-based categorization of the data. Secondly, cluster analysis is performed on the resulting categories to reduce their number to a manageable size.

Let (classifying) variable 1 be building size and variable 2 be climate. We select boundaries for each variable to generate an initial set of nine categories. This categorization is then imposed upon the database (e.g., NBECS or CBECS), and the score for each category is computed. For simplicity, we assume that the score is the average building energy intensity (KBtu/sq. ft). Table 8.1 shows a set of hypothetical average intensities for each of the initial matrix categories.

Table 8.1. Average Energy Intensities for Initial Matrix Categories

	Climate		
Size	Cold	Temperate	Hot
Small	200	100	115
Medium	140	80	110
Large	120	110	140

We then pursue an optimization procedure that combines categories, while at the same time preserving the continuity of size and climate dimensions. Let use consider how these nine categories could be condensed into four categories. We look for adjacent categories that have the most similar energy intensities. Such a procedure might begin by combining large buildings in the cold and temperate climate zones. These two categories have the shortest distance in terms of category means. A second step might combine small and medium buildings in the hot climate zone.

The cluster algorithm would also consider combining boxes or expanding boxes that have previously been joined. Thus, we might add small and medium buildings in the temperate zone to those same size buildings in the hot zone. In this example, a final combination step might add large buildings in the hot zone to those previously in the cold and temperate zones. The resulting categories are show as the grouped values in Table 8.2.

Table 8.2. Categories for Final Matrix Categories

	Climate		
Size	Cold	Temperate	Hot
Small	200	100	115
Medium	140	80	110
Large	120	110	140

The resulting categories have a clear physical interpretation. The categories are

- small buildings (cold climate)
- medium buildings (cold climate)
- small and medium buildings (temperate and hot climate)
- large buildings.

Note that categories are chosen to maintain rectangular, or "box," dimensions. Thus, we cannot further combine categories 2 and 4 to eliminate one category. The objective of the cluster algorithm would be to maintain a uniform maximum distance between the categories, in terms of energy intensity, under the restriction of generating subsets of the initial classification.

The description above, however, provides a general approach without actually implementing a formal cluster algorithm. In the illustration above, the results of our hypothetical cluster analysis may be inconsistent with the desired objective. A number of other issues need to be explored to implement this approach. The algorithm needs to be structured to prevent very small or large categories from being generated. Even the simple example above suggests that the final set of categories is not independent of variable ordering used to combine categories. Different orders of the categories may be employed to determine whichever is optimum. Finally, the clustering algorithm could use a segmentation strategy rather than the combination strategy describe here.

8.3 Prototypical Commercial Buildings in Prior Studies

Small sets of prototypical buildings have been developed for a number of commercial modeling and standards development activities. Usually, professional judgment was used to ascertain that such buildings were representative of specific building type (i.e., offices,

stores, and schools). The matrix approach was generally followed with the key determinants being building size, HVAC system, and climate.

8.3.1 ASHRAE 90.1 Building Standard

The initial development of the recently issued ASHRAE 90.1 building standard (ASHRAE/IES 1989), and the associated Federal Commercial Building Standard was begun in 1983. In this project, plans for ten existing buildings were selected from a larger set based on their ability 1) to generally represent more-or-less typical buildings, and 2) to be able to test various aspects of the proposed standards. Each of these buildings was reconfigured with two to four typical HVAC systems and then simulated for five climate zones (cities). Table 8.3 shows the general characteristics of the buildings used in the project.[a]

Each of the buildings in Table 8.3 was simulated for five climate zones. The primary cities representing these zones and the basic descriptors were

1. El Paso, Texas	Hot, dry climate
2. Lake Charles, Louisiana	Hot, moist climate
3. Madison, Wisconsin	Cold climate
4. Washington, D.C.	Significant heating and cooling loads
5. Seattle, Washington	Minimum heating and cooling loads

8.3.2 COMMEND Version 1.0

Jackson developed a set of prototypical buildings for Version 1.0 of the COMMEND model for EPRI. The results of a set of structured heat load simulations for these buildings formed the data for his technology-cost function estimation (see Section 5.0). Jackson recognized the issue of defining a prototypical building. Without available resources to address this issue, his approach was to judgmentally determine a small set of prototype buildings. Table 8.4 shows the characteristics of the buildings used in this work.

(a) The apartment building in standards projects is omitted in the list. For our purposes, this is a residential building.

Table 8.3. Buildings Used to Test ASHRAE 90.1 and Federal Commercial Standard

Description	Size (sq. ft)	HVAC Systems	Weekly Hours
Small Office	2,500 1 floor	VAV-DX Rooftop Multizone DX Rooftop Hot Water Heating	50-60
Medium Office	49,500 3 floors	Water/Air Heat Pumps Dual Duct/VAV CV-Reheat Air/Heat Heat Pumps	50-60
Large Office	700,000 38 floors	VAV-Reheat Add Double Bun. Chiller Packaged VAV	50-60
Large Retail	164,200 2 floors	Constant Volume Constant Vol.-Reheat PACKAGED (VTCV-DX) Rooftop	80-90
Small Retail	11,760 1 floor	Packaged (VTCV-DX) Rooftop Packaged (VAV-DX) Rooftop	80-90
Hotel	315,000 10 floors	Four-Pipe Fan Coil Add Double Bun. Chiller	168
Warehouse	40,750 1 floor	Gas-Fired Unit Heaters Hot Water Coils	50-60
School	123,700 1 floor	Packaged (VAV-DX) Rooftop Four-Pipe Fan Coil	40-50
Church	14,150 1 floor	Packaged VTCV-DX Four-Pipe Fan Coil	60-80

Table 8.4. Buildings Used in Development of COMMEND Version 1.0

Description	Size (sq. ft)	HVAC Systems	Weekly Hours
Office	40,500 3 floors	Multizone (CV) Add Rotary Heat Exchangers	50
Retail	86,000 1 floor	Constant Volume Add Rotary Heat Exchangers	70-80
Hospital	180,000 4 floors	Four-Pipe Fan Coil Add Heat Exchanger	168
School	40,000 1 floor	Four-Pipe Fan Coil	30-40

8.3.3 CEDMS

Jackson employed 10 prototypical buildings in the engineering analysis to support the forecasting model for the New England Power Pool. Table 8.5 provides a summary of aspects of these buildings. Where two HVAC systems are listed, the second is intended to represent a typical new building.

The heat load analysis in CEDMS was conducted with weather data for three locations in New England. Annual heating degree days for these locations are 7552, 6474, and 5840.

Table 8.5. Prototypical Buildings in CEDMS (NEPOOL Version)

Description	Size (sq. ft)	HVAC Systems	Weekly Hours
Office	15,000 1 floor	Multizone VAV	50
Retail	86,000 1 floor	Four-Pipe Fan Coil Single Zone	80-90
Grocery	26,300 1 floor	Single Zone VAV	70-80
Restaurant	5,000 1 floor	Single Zone	110-120
Warehouse	20,000 1 floor	Single Zone	60
Refrigerated Warehouse	20,000 1 floor	Single Zone	168
School	28,900 1 floor	Four-Pipe Fan Coil	50
Nursing Home	60,000	Four-Pipe Fan Coil 1 floor	168
Hospital	100,000 4 floors	Multizone	168
Hotel/Motel	57,800 2 floors	Four-Pipe Fan Coil	168

9.0 Building Energy Simulation Codes

An engineering-based building energy simulation tool is a vital component of the overall commercial sector energy model. The simulation model provides a method of evaluating the energy consumption aspects of specific technologies under various building configuration, operating schedules, and climates.

As discussed in Section 4.0, we view the choice of such a tool as important from the standpoint of the overall model development. Although we still envision that the building energy simulation tool will stand apart from the projection model, the increasing capability of microcomputers also increases the feasibility of incorporating many features of the simulation tool directly within the projection framework.

9.1 Typical Framework of Building Energy Simulation Models

This section provides general background concerning the estimation of building energy consumption.[a] A common set of elements has evolved in developing engineering models of energy consumption. These elements are present in the most basic models as well as in the most sophisticated, time-dependent, hourly simulation models such as DOE-2. As Figure 9.1 shows, these elements comprise three major steps: 1) loads calculation, 2) secondary system calculation, and 3) primary system calculation. Each step is discussed in the following sections.

9.1.1 Loads Calculation

The loads calculation step involves calculating thermal loads within the building space. The principal sources of thermal loads are as follows:

- heat transmission through the building envelope (roof, walls, and windows)
- solar heat gains
- internal heat gains from lighting, equipment, and occupants
- air infiltration.

(a) This section draws heavily from Knebel (1983).

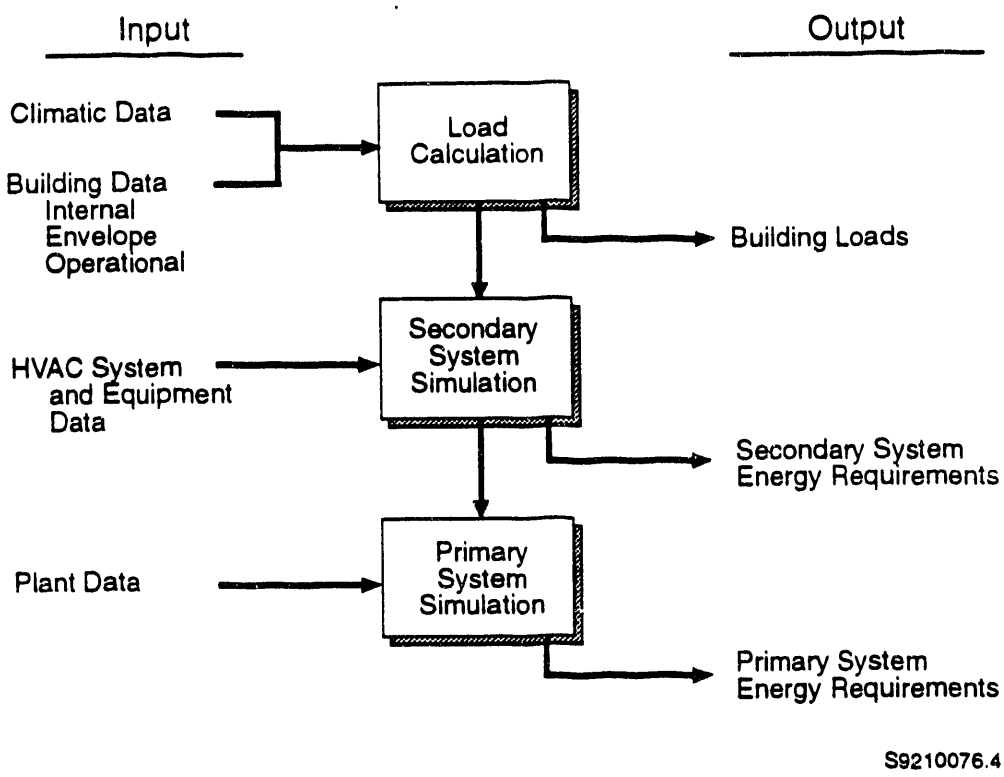

Figure 9.1. Simplified Schematic of Steps Involved in Estimating Building Energy Use

Thermal loads are calculated for given building operating conditions and weather. These loads are to be distinguished from design loads, which are used to size the HVAC equipment. The design loads are estimates of the extreme heating and cooling loads that might occur. For cooling, the design load is often found when the maximum solar radiation, the design maximum temperature (that temperature which is exceeded for only a specified percentage of hours in a typical year, usually 2.5%, as suggested by ASHRAE [ASHRAE/IES 1989]), and the design humidity all occur simultaneously. The design heating load is based on the design minimum temperature (defined similarly to the design maximum temperature).

9.1.2 Secondary System Simulation

The secondary system is the delivery mechanism by which conditioned air is transported into the occupied areas of the building in order to achieve comfortable temperature and humidity conditions. The secondary system becomes a critical component in

determining the energy requirements of commercial buildings, particularly in larger buildings where thermal loads may vary significantly in different areas (zones) at the same point in time.

Two general types of secondary systems have evolved in commercial buildings. In a central system, there is usually only one primary source of heated and cooled air for the entire building. To meet the diverse loads of the various areas of the building, the secondary system often must mix cooled and heated air in various proportions to achieve a specified temperature in each separate area. The degree to which the use of offsetting heated and cooled air streams can be minimized plays an important role in determining the overall HVAC efficiency of the building.

The second type of system is a zonal system. In this system, self-contained units are installed either within the building or on the roof. These units both generate and deliver heated or cooled air to the area served by the units. Because zonal systems serve relatively small areas of the building, the need for offsetting heated and cooled air at the same time is reduced. However, the primary units generating the heated or cooled air are usually smaller than those for central systems, with generally lower conversion efficiencies.

9.1.3 Primary System Simulation

The primary system consists of energy conversion equipment, including boilers, furnaces, chillers, and heat pumps. This equipment supplies the heated and cooled water or the steam to coils located in the secondary system air streams. The primary systems respond to loads placed upon them by the secondary system. Fossil fuel or electrical energy is the input required by the primary system.

A key issue in simulating the primary system is part load operation. In most types of equipment, maximum efficiency is achieved at generally high operating rates. The system becomes less efficient whenever operating below this level. Several procedures have been developed to estimate the efficiencies at various operating rates for basic types of conversion equipment.

9.2 Overview of Candidate Building Simulation Codes

The following subsections briefly describe some candidate building simulation codes.

9.2.1 DOE-2

The most widely used building energy simulation code for commercial building is DOE-2. The model was originally developed at LBL in the late 1970s and has undergone continual revisions since that time. The most current production version of the model is labeled as Version 2.1D.

DOE-2 can simulate large and complex buildings. The buildings can be divided into many different zones which are capable of independent heating and cooling control. DOE-2 calculates the hourly energy use of a building given hourly weather data, building location, construction materials, operating schedule, and HVAC systems. The program has five computational sections. The first three correspond to the discussion in Section 9.1. Two other components of the model deal with the areas of solar and economics.

Because DOE-2 is an hourly load model, a run involves simulation over 8760 hours in a year. This feature, as well as the complexity of its loads and systems routines, lead to long run times. On a 16-Mhz 386 PC, the average solution times to simulate one of the 20 prototypical office buildings from PNL's categorization study for GRI (Briggs et al., 1987) generally fell between 30 and 45 minutes. These buildings were configured with approximately 15 zones and up to four different HVAC systems.

The advantages and disadvantages for using DOE-2 are as follows:

Advantages

- widely used, public domain, very credible as simulation tool
- handles time dependencies (mass effects, solar gains)
- daylighting capability

Disadvantages

- large number of input parameters, minimum of several hours to develop input files
- long run times, even on today's fastest microcomputers
- menu interface, very difficult to incorporate in a more general model.

9.2.2 ASEAM

A simplified energy analysis method (ASEAM) is a modified bin method program for calculating the energy consumption of residential and simple commercial buildings (ACEC Research and Management Foundation 1987). A bin method involves calculating instantaneous building loads and energy consumption for various outside temperature ranges or bins (e.g., 76 to 80°F). To calculate annual energy consumption, the energy consumption results for each bin are summed, using the number of hours each year that fall into the bin as weighting factors. The modified bin method in ASEAM employs approximation procedures to address the questions of time dependent and solar loads.

A bin method is much faster than an hourly simulation method because it assumes that the building behaves the same for all hours in a bin. The heat load, HVAC, and plant calculations need only be computed once for each bin. Using 5 degree bins, only 20 to 30 sets of calculations need to be performed (e.g., -29 to -25°F, through 106 to 110°F).

The reduced computing time needed for the bin method, as well as the substantially simplified nature of the input requirements (as compared with DOE-2), were primary motivations behind ASEAM development. The model was developed with funding from OBT and FEMP. FEMP viewed ASEAM as being more accessible by federal building energy managers to evaluate conservation options in existing building. In addition to its less-demanding computer requirements, ASEAM has a number of user-friendly features, such as error checking, help messages, and default values.

On an AT-class computer, ASEAM can perform calculations for a typical five-zone building in seven minutes. Up to 10 thermal load zones with different secondary HVAC systems assigned to each can be specified. The model can simulate thirteen different HVAC systems, five heating plants, and seven cooling plants.

The advantages and disadvantages of using the ASEAM are listed below:

Advantages

- fast compute times, as compared with hourly simulation approach
- menu-driven input screens
- public domain; fairly widespread use

Disadvantages

- programmed in BASIC; difficult to modify
- relatively slow, as compared with use of more modern language
- cannot simulate hourly peak loads.

9.2.3 FEDS

A new building energy simulation tool is currently being developed at PNL as part of a comprehensive system to support energy planning and acquisition activities at federal facilities. The system, called FEDS (Facility Energy Decision Screening), is a comprehensive, fuel-blind approach for analyzing energy needs. FEDS identifies the highest value energy projects and implements those projects. While FEDS is intended for use in federal agencies and at federal installations, the elements of the energy simulation model can be applied more generally to other commercial buildings.

FEDS is being developed on a multilevel basis. The top level is most relevant to supporting the engineering framework for an improved commercial sector forecasting model. At this top level (Level 1), FEDS is a menu-driven PC-based software program that can be used by agency or installation managers to target the most promising energy conservation projects (e.g., lighting retrofit and utility rate negotiations) and to estimate investment requirements and potential energy and cost savings. Level 1 depends upon numerous assumptions about the typical federal facility, with only minimum energy price and installation configuration information needed as input. All major end uses are considered, and all significant interactions between end uses and energy conservation options are accounted. The output of this top-level screen is a preliminary indication of what actions will be the most cost effective.

At lower levels, FEDS will be implemented by those staff who can work with installation staff to acquire more detailed data, conduct more sophisticated analyses, and better target the energy projects that have been identified by the Level 1 analyses. These analyses will be performed using a number of tools, including software developed specifically for FEDS and other existing software programs, databases, and algorithms. These audit-based tools have much less relevance to a general policy model.

The PC-based energy simulation tool in Level 1 of FEDS uses what may be termed a compact hourly simulation approach. A twenty-four hour profile of loads and consumption simulated for each month. This feature permits a more realistic treatment of building mass effects, solar gains, and peak loads than can be achieved with ASEAM. The use of

monthly average profiles allows the model to be run much more quickly than DOE-2. The model is coded in "C," which allows a very modular structure for continuing enhancement.

The Level 1 FEDS model will differ from other energy simulation codes in that it contains an explicit optimization mode. Based on performance and costs, FEDS seeks an optimum set of technologies or retrofit options. The optimum sets will change automatically within the program as energy prices are varied. To achieve this capability, an extensive database of conservation options and associated costs has been developed.

The Level 1 FEDS tool has one other attribute that is very important from the standpoint of supporting a general building conservation policy model. The tool is being designed from the outset to be able to operate in a data-poor environment. The intent of Level 1 software is to provide an indication of conservation potential for a federal facility (e.g., military base) that may contain hundreds of buildings. Only the most general information may be available about each building, such as fuel type, size, and age. Other building attributes must be inputed. At this point, a number of these attributes have been imputed from NBECS information.

In comparison with DOE-2 or ASEAM, the Level 1 FEDS tool is designed to quickly assess conservation potential for multiple buildings without highly specific building information. This capability adequately matches with the building simulation component of the overall commercial forecasting model that will be provided.

Some of the advantages and disadvantages of using the FEDS approach include the following items:

Advantages

- incorporates database of technology performance and cost data
- uses an optimization mode to select optimal sets of technologies
- is coded in "C" to facilitate enhancements and transportability
- has many default values based on NBECS
- treats building mass, solar gains, and peak loads

Disadvantages

- only a few basic HVAC systems available

- application is for retrofit rather than new buildings

- unknown computer time requirements to implement optimization.

9.2.4 NBECSIM

NBECSIM (Nonresidential Building Energy Consumption Simulation) is a model to estimate HVAC and lighting loads for sample buildings in EIA's NBECS building sample. The model was implemented for office buildings from the 1979 NBECS (EIA 1981). NBECSIM was the tool used to estimate building loads for use in categorizing the office building sector in United States.

The engineering framework for NBECSIM was taken from the ASHRAE-supported report, *Simplified Energy Analysis Using the Modified Bin Method* (Knebel 1983). This report was the product of Technical Committee (TC) 4.7, the Energy Calculations Committee. As the title of the TC 4.7 report indicates, the basic approach is to use a bin method for estimating building energy consumption (see Section 9.2.2). The report provided a series of FORTRAN codes of the bin procedure for four major types of secondary HVAC systems. Annual energy consumption is computed for each system for heating, cooling, and fan energy.

NBECSIM links the bin codes in the TC 4.7 report with the sample of office buildings in the 1979 NBECS (EIA 1981). After reading some sixty variables for a given sample NBECS building, NBECSIM first translates this information into the input required by the bin procedure. This translation depends upon a variety of input rules that were developed from engineering fundamentals and professional judgment. Annual consumption estimates per square foot become the final outputs of the program.

The complete set of 1139 buildings could be simulated in just over an hour on an AT-class microcomputer. Some analysis software was developed for the model, principally a display program to allow a user to easily compare the results of alternative simulations. The model is documented in PNL's office categorization study report for the GRI (Briggs et al. 1987).

Some advantages and disadvantages of using the NBECSIM are listed below:

Advantages

- simulation codes directly linked representative sample of office buildings

- run time is sufficiently fast to perform simulations for entire national sample (NBECS) for one building type

- billing data from NBECS provides means of calibrating model

Disadvantages

- model lacks many engineering-related features of competitors
- limited number of HVAC systems
- to date, implemented only for office buildings.

10.0 Projecting Floor Space Stock

The forecasting of future commercial floor space is a critical element in long-term energy demand forecasting. Because floor space enters multiplicatively in the energy projection equation, it is critical to developing plausible absolute projections of energy use. An explicit understanding of the floor space projection is vital when attempting to compare energy projections from various models.

Even when the major use of the model is to evaluate various policies rather than generate unconditional forecasts, floor space remains a key variable. The projection of floor space determines how many new buildings could be built in coming decades, a fraction of which will be subject to various standards. The composition of the new building stock, both by climate region and by building type, is also important for defining markets for new building technologies.

This section first examines the general approaches that have used by previous analysts with commercial sector energy models. The latter part of the section will describe how the major models have thus far dealt with this issue.

10.1 General Approaches

Several approaches have been used to forecast floor space stocks and additions. The three most common have been

- stock demand
- investment (additions) demand
- constant stock ratio.

10.1.1 Stock Demand

The stock demand equation for floor space is most generally specified in terms of the neoclassical investment model, which has had a long history in empirical investigations of investment demand. In its most general form, this specification posits that the demand for capital (here denoted by S [floor space stock]) is a function of the level of output and the cost of investment funds (or relative input factor prices). A simple representation of this specification is

$$S(t)^{*} = f[Q(t), r(t)] \qquad (10.1)$$

where $S(t)^*$ = desired level of stock in period t

$Q(t)$ = output in period t

$r(t)$ = cost of investment funds (function of interest rate and construction prices).

Empirical studies normally assume that the actual level of stock is adjusted toward its desired value only after a time lag. This is particularly relevant in the case of commercial buildings where design, site acquisition and preparation, and bid procedures can involve considerable time lags. The way these lags have been specified in the general investment demand literature has varied widely. In some cases, separate lag functions have been used for both output and interest rate variables. One popular specification, although one with statistical problems, is termed as a partial adjustment model. In this model, the magnitude of the change in stock depends upon its deviation from desired stock. Specifically,

$$S(t) - S(t-1) = c\,[S(t)^* - S(t-1)] \qquad (10.2)$$

When the expression for desired stock (Equation [10.1]) is substituted into Equation (10.2), we have an estimated form of the equation in terms of observable variables. These assumptions lead to an specification for stock in period t of the form:

$$S(t) = c\,f[Q(t), r(t)] + (1-c)\,S(t-1) \qquad (10.3)$$

10.1.2 Investment Demand

The investment demand approach concentrates strictly on explaining the level of investment, here translated as floor space additions. Generally, the same explanatory variables are used (output and the cost of investment funds):

$$A(t) = g(Q, r) \qquad (10.4)$$

Again, various lags can be used in conjunction with the explanatory variables. The principal difficulty with the investment demand formulation comes about in long-run forecasts. The additions forecasts still have to accumulated into a stock variable for use in the energy demand model. Because the addition equation is not derived from the demand for stock, there is no assurance in a long-run forecast that the resulting stock will be consistent with forecast levels of output or other activity variables. This can lead to implausible levels of the stock in future periods.

10.1.3 Constant Stock Ratio

The constant stock ratio can be considered a variant of the stock demand approach and differs in two ways. First, the constant stock ratio simplifies the demand function to be proportional to output or an activity variable (e.g., employment). Using other variables besides output is another dimension of this approach. Rather than deriving the formulation from a strict neoclassical point of view, the constant stock ratio approach can consider other input factors used in producing commercial services. In essence, the assumption is that these factors are strict complements in the production process. The approach also goes outside the production function framework in seeking activity variables. Therefore, using school-age population in explaining educational floor space recognizes that measures of educational output do not exist.

Secondly, it ignores the adjustment lags between desired and actual stock. As such, it focuses on long-run relationships. Jackson and Lann (1982) specified this approach to include a trend term with respect to the stock/activity ratio. Using employment as the activity variable, his formulation can be represented as follows:

$$S(t) = F\, e^{r(t-t_o)}\, E(t) \tag{10.5}$$

where S = floor space stock

t = forecast period

t_o = most recent year of historical floor space

F = floor space per employee in base-year period t_0

r = annual growth rate of F

E = employment.

Jackson maintains that the data requirements are less stringent in this approach as compared with the stock demand approach. An estimate of F can be obtained for a base year and E for a forecast year. An estimate of r from another source can be used or can be set judgmentally. If $r = 0$, Equation (10.5) can be alternately viewed as simply making floor space increase proportionately with employment.

Table 10.1. Summary of Floor Space Forecasting Approaches in Selected Commercial Models

Model	General Approach	Comments
ORNL Regional Model (Cohn et al. 1981)	Stock demand floor space is log-linear function of population/income.	Cross-section estimates within each of 10 federal regions.
Northwest Public Power Council (Johnson and Lann 1982)	Constant stock ratio floor space/activity ratios developed from CEC study and applied to northwest.	Used NBECS and F. W. Dodge[a] data to evaluate changes in historical CEC study ratios.
COMMEND 1.0 (Lann et al., 1985)	Model coded to accept either parameters of floor-space-per-activity approach or exogenous additions.	For floor space per activity ratios, Jackson recommends CEC data.
Commercial Sector Energy Model (EIA 1984)	Stock demand floor space function of population and income by region.	Iterative procedure used to calibrate depreciation rate.
CEDMS--NEPOOL[b]	Constant stock ratio uses a variety of sources to estimate ratio--preferred estimate from NBECS in 5 of 20 building types.	Stock forecast is directly proportional to forecast of employment or activity variable.
PNL Commercial (Brookhaven National Laboratory)	Stock demand aggregate floor space function of function of GNP, constant shares by building type for new construction.	Calibrates historical F. W. Dodge additions to NBECS vintage data.
COMMEND 3.2 (Regional Economic Research 1991)	Model coded to accept either parameters of floor space per activity approach or exogenous additions.	For floor space per activity ratios, Jackson recommends cost of conserved energy data.

(a) The F. W. Dodge Division is a section of the McGraw-Hill Information System Co., New York, New York.

(b) Jackson, J. R. 1988 (not publicly available). *CEDMS - PC User's Guide and Reference Manual.* Prepared for New England Power Pool (NEPOOL) by Jerry Jackson and Associates, Chapel Hill, North Carolina.

10.2 Approaches Used in Previous Commercial Models

Table 10.1 summarizes the floor space forecasting approaches used in previous and currently maintained commercial models. The differences in approach can generally be attributed to three factors: 1) data availability, 2) source of driver variables, and 3) resource constraints. Data availability generally refers to the existence of survey-based estimates of existing stock and the availability of annual additions data (usually from F. W. Dodge). The source of driver variables influences model structure in that often the commercial energy model is linked to a long-term economic model. The sectoral disaggregation and time horizon of the economic model will influence the nature of the floor space equations in the commercial energy model.

The long-term policy oriented models developed by ORNL, PNL, and EIA have generally favored a stock demand approach. These models have used basic economic and demographic variables to drive the floor space equations, where GNP, personal income, and population are key variables.

The more recent models developed by Jackson and Lann (1982) have tended to use the floor-space-per-activity approach. For specific utility service areas without a benchmark survey of floor space, this approach is the only alternative. Floor-space-per-activity ratios are estimated from the best available source (i.e., NBECS or a neighboring state) and then use to develop floor space estimates for a base year. The values of the activity (e.g., employment, school-age population) are then used to develop historical and projected values of the stock. Gross additions are determined by taking the change in the stock and adding an estimate of replacement construction.

Jackson and Lann (1982) recognized the simplicity of this approach and the issue of whether the floor space per activity ratios are constant over time. In the study for the NWPPC in 1982, some attention was given to what some reasonable values of r might be. National floor space stocks were constructed for six building types for 1965 and 1979. These estimates started with the 1979 benchmark estimates from the NBECS (EIA 1981) and then worked backward with F. W. Dodge data additions.

Historical time series on employment are also required. Employment estimates were taken from national aggregated county business patterns information provided by the U.S. Census Bureau.

10.3 National Historical Floor Space Estimates

To support its commercial sector energy modeling activities, PNL has recently completed new estimates of historical commercial floor space and projections of floor space to

the year 2010. Historical estimates of commercial building floor space are essential to any evaluation of broad changes in commercial sector energy efficiency. Projected floor space is a key element in determining the relative importance the commercial sector will have in the nation's future energy picture.

The four surveys of commercial buildings conducted by the EIA since 1979 have provided estimates of floor space, by building type, for 1979, 1983, 1986, and 1989 (EIA 1981, 1985, 1988, and 1991). Differences in sampling procedures make it difficult to make comparisons over time among the surveys. Neither EIA nor any other government agency publishes time series estimates of floor space in the commercial sector.

10.3.1 Background

To support the first engineering-economic model of the commercial sector, Jerry Jackson and William Johnson at ORNL developed annual floor-space estimates for ten building types in 1978 (Jackson and Johnson 1978). The basic source of information for their study were the data on new additions of square footage collected by the F. W. Dodge Division of McGraw-Hill. Using a perpetual inventory method, a floor space stock was constructed from 1925 forward. Floor space was assumed to leave the stock (demolitions) following a logistic retirement pattern with a 45-year half-life (i.e., half the floor space constructed in any year is expected to disappear from the stock in 45 years).

The first NBECS conducted by EIA in 1979 was a milestone in that it was the first comprehensive national survey of commercial buildings to be taken in the United States (EIA 1981). EIA's estimate of 43 billion square feet as of January 1, 1980, was about 40% higher than the then best estimates by ORNL. The higher estimate was generally acknowledged to be largely the result of underreporting of new construction by F. W. Dodge.

In 1986, EIA sponsored SRA Technologies Corporation to construct historical floor space estimates and to develop a methodology for forecasting future floor space (SRA Technologies 1986). SRA used the special demolition/conversion file created from the 1983 NBECS (EIA 1985) to construct retirement rates for six building classes and the four census regions. Using these rates, and annual vintages of floor space (as published in the 1983 NBECS [EIA 1985]), time series of floor space were backcast from 1983 to 1960.

10.3.2 New Floor Space Estimates Benchmarked to 1989

The floor space estimation procedure used by PNL combines elements of both of the above approaches. A demolition function was estimated from the special demolition/conversion file used by SRA. Additions data from F. W. Dodge were used to interpolate over time the vintage totals from the 1986 NBECS (EIA 1988). In comparison to the SRA

approach, the F. W. Dodge data were assumed to capture the year-to-year fluctuations in construction activity more accurately than the annual vintages totals reported by the NBECS. As in the SRA methodology, stocks for historical years were backcast from the benchmark totals in the 1989 NBECS (EIA 1991).

The demolition function was based on a regression analysis of the observed demolition rates by vintage between 1979 and 1983. A logistic function was fitted to minimize the squared errors between predicted and actual demolition rates for five vintages: before 1900, 1901 through 1920, 1921 through 1945, 1946 through 1960, and 1961 through 1979. Unfortunately, the sample size of the demolished commercial buildings was too small to allow separate functions to be estimated by building type. Accordingly, a single function was estimated for all buildings. Given the actual pattern of demolitions between 1979 and 1983, the estimated logistic function implies a considerably longer building life than previously assumed. The half-life implied by the estimated function is a little over 90 years.

The sample sizes in the NBECS are not large enough to accurately estimate annual additions, either by building type or all buildings together. The annual construction data, by square footage, collected by F. W. Dodge were used to allocate the 1961 through 1989 vintage, by building type, reported in the 1989 NBECS (EIA 1991). The reputed underestimation of the F. W. Dodge figures is not a serious weakness in this application, as long as the bias has remained fairly constant over this period. Excluding hotels (which are not part of the Dodge commercial data) total additions reported by F. W. Dodge from 1961 through 1989 are 25.6 billion square feet. The 1986 NBECS estimates a total of 32.0 billion square feet for the same period for all building types, excluding lodging (EIA 1988).

With the estimated logistic function and recent floor space additions, a historical floor space series was then constructed. As in the SRA study, this is an iterative procedure, starting with the NBECS benchmark in 1986 and moving backwards to 1960. In general terms, the formulation employed is

$$\text{Stock}(t-1) = \text{Stock}(t) - \text{Additions}(t) + \text{Demolitions}(t) \qquad (10.6)$$

The first year of this procedure estimates the stock for 1985 (year t-1).

As mentioned above, the stock in year t (1989) is taken from NBECS. Additions are based on the F. W. Dodge data, calibrated to 1961 through 1989 vintage totals. Demolitions are based on the detailed stock by annual vintage from the 1986 NBECS (EIA 1988). They are calculated by using the logistic function to calculate, in effect, the level of the stock in each vintage that would have existed one year earlier. Floor space series were constructed for the twelve building types used in the PNL commercial sector model.

10.3.3 Floor Space Projections

The historical time series of floor space were used to develop a methodology to project future floor space. Ideally, either floor space or changes in floor space can be linked to key determinants of investment--the level of activity (e.g., employment, school-age population, and total population), interest rates, and perhaps the existence of special government programs. Separate econometric equations would be developed for each building type.

To support the 1991 baseline commercial energy projections for OBT, the approach to projecting future building stocks is much simpler than that described above. One equation is estimated to predict changes in total floor space. Floor space additions by building type are then based on an allocation procedure that essentially holds the shares of total additions by building type at the observed values for the 1980s. In part, this simple methodology was dictated by available time and resources for the task. However, the end result is consistent with historical trends and which provides reasonable results for a long-range projection to the year 2010. Many of the short-term econometric specifications of nonresidential building investment presently used in some of the macroeconomic models would not display these long-term properties.

10.3.4 Projecting Total Floor Space

The first element of the projection procedure links changes in total floor space to changes in GNP. Based on the time series of total floor space benchmarked to the 1989 CBECS (EIA 1991), the following equation was estimated over the period 1963 through 1989.

$$\Delta \ln(S) = \underset{(8.3)}{0.106}\ \Delta \ln(GNP) + \underset{(45.3)}{0.861}\ [\Delta \ln(S)]_{t-1} \quad R^2 = 0.882 \quad \text{(t-statistics)} \qquad (10.7)$$

The change in the logorithm of the floor space stock (S) closely approximates the percentage change in the stock. Any change in the growth rate of GNP translates into a change in the growth of total stock. The first estimated coefficient implies, for example, that a recession that depressed the growth in GNP by 4% would reduce the growth in stock in the same year by nearly one-half percent (4 * 0.106). The presence of the lagged (log) change in stock is derived from the assumption that any change in GNP growth would change the growth rate in stock with a time lag.

The sluggishness of the adjustment of nonresidential building investment owes largely to the long planning cycles required for large commercial projects. In addition, some components of nonresidential construction have historically tended to be counter-cyclical. Table 10.2 contrasts the behavior of total building stock and GNP during the last two severe recessions.

Table 10.2. Annual Percentage Changes in GNP and Total Floor Space (1973 through 1974 and 1981 through 1982)

	1973	1974	1981	1982
GNP ($1982)	5.2	-0.6	2.2	-2.5
Total Floor Space	3.4	2.8	2.2	1.7

The R^2 of the equation suggests that this simple model captures much of cyclical behavior of net additions to the stock. The coefficients of the equation can be also be used to estimate the long-run response in the growth rate of floor space to any step change in the growth rate of GNP. The long-run response is approximately 0.76. (This value, based on a partial adjustment specification with a lagged dependent variable, is computed as 0.106/(1.0 - 0.861). For example, if GNP is projected to grow at 2.0 per year in the coming decades, total floor space by this model would grow at 1.5% per year.

The actual projection of total floor space was based on the growth rate of GNP made by DRI and was published in the 1991 Annual Energy Outlook (Appendix A--Reference Case Projections). GNP projections were published to the year 2000. Beyond 2000, GNP was assumed to grow at a constant 2.1% per year. Using the estimated equation and starting at the 1989 CBECS benchmark of 63.2 billion square feet, total floor space was projected to rise to 77.7 billion square feet by 2000 and 92.2 billion square feet by 2010 (EIA 1991).

10.3.5 Composition by Building Type

The equation to project aggregate floor space yields net additions to the stock in each year. The demolition function described above can be used to project annual demolitions. Floor space by building type is developed by sharing out gross additions, the sum of net additions and demolitions.

Shares of new construction by building type are based on average shares for the period 1980 through 1986. One important adjustment was made before these shares were used to allocate total additions through 2010. Office construction during the 1980s is widely viewed to have been largely driven by the favorable tax treatment initiated in 1981 (now repealed). The rise in office vacancy rates in most metropolitan areas will likely depress new office construction for some years to come. Accordingly, although the percentage of gross additions in office buildings was 25% of total construction during the 1980 through 1986 period, this figure was reduced to 20% for the projection period. The relative shares of the other building types were maintained at the average from 1980 through 1986.

10.4 Issues and Proposed Approaches

In this section, we will discuss what we judge to be the most relevant outstanding issues and some approaches with regard to floor space estimation.

10.4.1 Projection Approach

As the review above indicates, the existing commercial models have been divided roughly equally in their use of the stock demand versus the constant activity ratio approach. In our view, the preferred approach in an enhanced commercial model is the stock demand approach. The stock demand approach recognizes that the desired level of stock depends on more than a single determinant. The levels of output, relative factor prices, and compositional effects will all play a role in influencing the long-run levels of floor space.

Although the constant activity ratio approach (as formulated by Jackson) can encompass trend changes in the ratio, there still remains little empirical evidence regarding historical changes in the ratios. Projection of the ratios would likely rest heavily on historical analysis. If we make the effort to construct historical floor space series to evaluate the ratios, we may just as well use these series to estimate the complete stock demand model.

The exact specification of the stock demand equation will depend upon the overall structure of the integrated model. The equations should be estimated with the same variables that will be available in the forecast period.

10.4.2 Regionality

The issue of what regions will be used in the enhanced commercial sector model will bear heavily on the approach taken for estimating floor space. The coverage of the current CBECS at the census region is probably sufficient to provide satisfactory benchmarks for 1989 and for construction since 1960. At the census division level, however, the size of CBECS sample is probably not adequate to support benchmark estimates.

Without addressing the question of what level of regionality is optimal for the integrated OPA model, we would still recommend that historical floor space estimates be developed to the state level as far back as 1960. These estimates could be used as part of cross-section time series stock demand specification. Even as the integrated model is not likely to be disaggregated to the state-level, the state level stock estimates could be used as weights for building standards or climate variables.

10.4.3 Potential Use of DRI/F. W. Dodge Floor Space Estimates

Since the mid-1980s, a unit of DRI has maintained a proprietary commercial floor space database and forecasting service. The database contains county- and state-level estimates of additions and stocks from 1969 forward. These estimates are based upon the construction additions database maintained by F. W. Dodge. Both F. W. Dodge and DRI have both been divisions of the McGraw-Hill Company since the early 1980s. Ten-year projections of floor space also available from this service.

The availability of this service would appear to be an attractive alternative to DOE developing its own estimates. However, there are some substantial drawbacks to the use of this data:

1. The data are highly proprietary. F. W. Dodge goes to great pains to ensure this attribute. In prior work for GRI that used the DRI database for office floor space, PNL tried to relax DRI's demand that this data be kept confidential *in perpetuity*.[a] Therefore, this data cannot be published as part of model documentation. Although DRI staff suggest that, in certain circumstances, they will allow this information to shown indirectly or in part, all draft materials that show this information must be reviewed by DRI. The practical implications of this requirement include increased costs and delays.

2. The forecast horizon of the data is only ten years. DRI's major market for this data includes construction contractors and suppliers who do not need long-term forecasts. For national policy purposes, we need a methodology that will generate projections of floor space 30 to 40 years in the future.

3. The floor space estimates from DRI are not inexpensive. The set of historical and projected floor space estimates at the state level is approximately $30K. Although this cost may be less than what can be done by DOE itself, the marginal cost of future updates may be higher.

4. The DRI's normal cycle for updating the floor space estimates is annually. Should OPA require special runs for sensitivity analysis, the dependence upon an outside contractor may involve increased delays and higher marginal costs.

By themselves, points 3 and 4 above would not provide reason not to use the DRI information. However, points 1 and 2 (especially point 1) appear to argue strongly against this option.

(a) "Perpetuity," from a legal standpoint, is a concept that makes most lawyers uncomfortable.

11.0 Computer Hardware and Software

This section discusses hardware and software issues for further developing the model. These issues include 1) development cost, 2) transparency for future updates, 3) run time, 4) user interface, and 5) portability. By addressing some of these issues during the early stages of the model's development, we can perhaps avoid some of the problems that have been encountered in previous energy modeling projects.

A decade ago, the range of such issues would have been more sharply restricted. The vast majority of models were written in FORTRAN and implemented on a mainframe or minicomputer. The principal issue was the portability of the model among computers because slight differences in FORTRAN existed on particular computers. User interface usually was embodied in the text editor, which was used to change inputs in an ASCII (text) file and in the design of the tables of line printer output.

With the development of microcomputers and software, these issues have become more critical. The concept of the spreadsheet as an data organizational structure and simple computing environment has influenced more recent model building efforts. The computer screen on every analyst's desk has made graphics and menu-driven interfaces almost required elements to foster widespread adoption of energy or economic models.

The following sections present, in very broad terms, some of the hardware and software options that could be used in the model enhancement work. Some general recommendations are also indicated.

11.1 Computing Platforms

Mainframe computers remain an option for an advanced computationally intensive energy model. As microcomputers have gotten faster and more powerful, so have the large IBM, Control Data, Cray, and other mainframe computers. However, these computers still cause the same types of problems that were encountered a decade ago. Portability is the chief problem, as proprietary versions of computer languages sometimes inhibit transferring model codes and data from one type of computer to another. Development costs can be higher because of the amount of effort necessary to learn and work with each system's operating language. Finally, the mainframe computers generally do not provide the range of graphics and database software that are widely used in the microcomputer field.

Work stations fall between mainframes and PCs in terms of their overall computing capability. Perhaps the two largest vendors of these computers are Hewlett-Packard and

Sun Microsystems. These computers are designed for very computationally intensive tasks that usually involve some graphical output. As with mainframes, portability among these machines can be inhibited by the use of proprietary versions of languages for application development. For application programs coded in "C," one of the newer programming languages that has been developed during the 1980s, a common strategy is to develop the application on a workstation before moving it to a PC.

The PCs represent the dominant computing environment today for most energy analysts. Three variants of PCs can be distinguished: 1) Apple Macintosh, 2) older IBM-compatible computers based on the Intel 8086 and 80286 chips, and 3) newer IBM-compatible computers based on the 80386 (386) and 80486 (486) chips. The Macintosh machine provides superior graphical capabilities compared with the IBM-compatible machines because of the Intel chips. However, the Macintosh is relatively expensive and is not nearly as common in business and professional use. The number of new machines using the older 8086 and 80286 chips is declining. These machines are limited to 640K bytes of random access memory, which makes implementation of large programs difficult.

The computers using the 386 chip have become the entry-level computers in most business applications. These computers have the capability to address millions of bytes of memory, and they are faster than the older designs. The 486 represents the current frontier of IBM-compatible machines; this chip provides the same addressing capability as the 386. However, a machine based on this chip is roughly twice as fast as the one using the 80386; for numerically intensive applications the speed gain is even greater. The upcoming versions of machines based on the fastest (50-Mhz) versions of this chip will rival many of the work stations in terms of computational speed (i.e., between 20 and 30 million instructions per second).

Most of commercial sector energy models that were first developed on mainframe and minicomputers have been adapted for IBM-compatible microcomputers. The COMMEND, CEDMS, and PNL commercial model were all converted to PC versions during the period from 1986 through 1988. Since these conversions were performed prior to the introduction of the 386- and 486-based computers, the models were forced to fit within the small memory requirements of the older designs. In the case of the PNL commercial model, this meant pruning parts of the model dealing with peak loads and making other compromises with the original code.

During 1991, prices of microcomputers based on the 386 and 486 chips fell dramatically (25% to 35%). Complete systems based on the fastest production version of the 486 (33 Mhz) can now be purchased for less than $3000. At the lower end, systems

based on the slowest versions of the 386 chip are selling for $1500 or less. Further major cuts in the wholesale price of the 486 chip are expected during 1992, which will lead to even lower system prices.

Given the current and projected prices of the 386- and 486-based computers, we recommend that these computers become the standard computing platform for the enhanced commercial model. A suggested set of hardware requirements might include the following:

- 386 or 486 computer with numeric coprocessor
- 4 megabytes of random access memory
- 10 megabytes of hard-disk space
- VGA monitor.

This configuration will facilitate model development as well as allow the completed model to run in a reasonable time length. There is no economic rationale to shoehorn the model into what is now obsolete computer technology (8086 and 286 designs, including the original IBM-AT).

11.2 Software Environment

As mentioned at the beginning of this section, the earliest commercial energy models were programmed in the predominant mainframe scientific language, FORTRAN. In moving to the PC, several of these models have been converted to "C."

While the decision of what software to use in building an enhanced commercial model is primarily up to those in charge of the development, some choices may have long-term implications for continuing improvement of a public domain version of the model. Perhaps the most striking example of this situation involves an industrial sector that was developed in the early 1980s for DOE. The Industrial Sector Technology Use Model (ISTUM) is a large-scale, technology-based model. The model was programmed entirely in the APL code. Although APL is a computationally efficient language, its intensive use of mathematical notation and symbols makes it very difficult to read and understand the model code and to make code modifications. Experienced APL programmers are rare. The bottom line is that choosing APL to code this particular model has inhibited further development of the model structure.

In general, we would prefer the model to be coded in such a way as to 1) facilitate the coding and debugging process, 2) be transparent to other potential developers, and 3) produce an inexpensive, stand-alone, executable module that can be used by analysts who have no desire to change the model structure. Within these general requirements, we briefly discuss some of the potential software (language) environments that could be used for the enhanced commercial model.

11.2.1 FORTRAN

Although FORTRAN is not often used in microcomputer applications, its capabilities are still very strong to support computationally intensive models, such as the commercial end-use model. FORTRAN offers transparent matrix indexing and efficient machine code. A large-scale, global CO_2 emissions model currently being developed by PNL is being coded in FORTRAN. The FORTRAN compiler being used in this project is part of an overall system that allows the model to address the large memory capacity of the 386- and 486-based computers.

The advantage of FORTRAN, in terms of the above criteria, is that it can be written as generally transparent to other developers and executable modules can be generated. FORTRAN, however, is somewhat cumbersome in the overall coding and debugging process. It also does not incorporate many capabilities to provide a user-friendly menu interface.

11.2.2 The "C" Code

The "C" code is a lower level language than FORTRAN; individual statements are needed to perform many of the hardware level instructions. "C" is a structured language, as compared with FORTRAN. It places more constraints on the order of particular statements; it also forces the programmer to more explicitly define each variable. These features help make "C" programs more self-documenting and accessible by other "C" programmers. On the other hand, the language itself is more complex than FORTRAN and is not as easy for nonprofessional programmers to learn.

Because "C" is a lower-level language, it has many features that allow direct manipulation of the hardware. This aspect gives the language the capability to generate menus, input screens, and graphical output. These advantages are likely behind the conversions of COMMEND and CEDMS to "C." However, compared with FORTRAN, "C" falls short in the computational arena. For example, "C" does not support doubly indexed arrays. For COMMEND, special procedures have to be invoked to support matrix calculations. This deficiency in "C" inhibits enhancements of existing models by others not involved in the original development process.

11.2.3 Spreadsheets

Spreadsheets are perhaps the seminal software application of the microcomputer revolution. The spreadsheet allows the user to directly view data within a rectangular grid and to perform calculations with that data. The more advanced spreadsheets contain simple database management functions and graphical capabilities. A type of programming language has been developed for spreadsheets (introduced by the LOTUS Corporation) that involve macros. Macros are used to invoke frequently used sequences of commands using only a few key strokes.

Simplified energy models have been built within spreadsheet environments. EIA built a series of simplified sectoral energy models within spreadsheets in the mid-1980s. PNL has developed a simple spreadsheet model to estimate the energy savings from various OBT R&D programs.

Spreadsheets offer some advantages over programming languages. In small applications, spreadsheet coding is often transparent. One can simultaneously view the data and the type of operations to be performed on that data. Macros can be used to move the user to various parts of the spreadsheet, which can then act as input screens. The graphical functions in the most advanced spreadsheets are very powerful and enhance the analytical usefulness of the model. Portability is not an issue with spreadsheets as spreadsheet software is relatively inexpensive and operates on all IBM-compatible computers.

With large amounts of data, as in the case of a disaggregated end-use energy model, it is very difficult to move around the spreadsheet to locate specific items. There are no matrix commands within the spreadsheet; separate formulas must be entered for each element in the array (although repeat-type functions exist for this purpose). The design of spreadsheets does not permit them to perform matrix calculations at anywhere near the speed of a programming language. Spreadsheets are also not conducive to changes in model structure. In our application, we would require that the number of technologies for a specific building prototype are capable of being changed by the user. This type of change is very difficult to implement within a spreadsheet. All in all, spreadsheets would not provide an easy-to-use and efficient software environment for the type of commercial energy model that we have described in earlier sections.

11.2.4 GAUSS

The GAUSS matrix programming language was first developed in 1984 by Aptech Systems. GAUSS is a fast interpretive language and was designed to simplify the writing of efficient codes for serious numerical computation. The basic unit within the language is a matrix that is automatically dimensioned. There are host of high-level numerical

functions that are automatically part of the language. Versions of the language are now available for 386 and 486 computers. These versions can provide a large workspace, as the memory limits of the computer permits.

GAUSS provides a user-friendly environment, thus, meeting the first criteria listed above. All variables can be displayed from the GAUSS command level; there is no need to dump values in to a file or screen, as with FORTRAN. A built-in editor allows the user to quickly make changes in the model code and to re-run the model. Several levels of graphics capabilities are available. A GAUSS application can be extended by defining specialized procedures in the language or by including existing FORTRAN, "C," or assembler code.

As mentioned in Section 5.0, GAUSS was used to test concepts of the technology choice module. The automatic matrix dimensioning aspect of GAUSS would be particularly useful in this part of the model, where the number of potential technologies would differ by building type or as more information became available.

The syntax of the language is straightforward, which would facilitate modifications to the model by others as well as the original developers. The cost of the complete GAUSS language for the 386 and 486 computers is $900. An executable module can be produced from GAUSS and can be transferred to non-GAUSS users for a nominal charge.

A current deficiency of GAUSS is that it does not offer a window-like screen input capability. Although a spreadsheet could be used for this purpose, the data would have to be transferred to GAUSS via ASCII files. Aptech Systems suggests that capability is currently being added to GAUSS that would allow it to directly access relational databases (such as DBASE or PARADOX).

11.2.5 Speakeasy

Speakeasy is a high-level array-oriented language and data analysis system. It was originally developed on IBM mainframes in the early 1970s. The range of functions in Speakeasy exceeds that of GAUSS, particularly in the flexibility of indexed arrays. Speakeasy was used by the Federal Reserve Board staff to build an advanced set of econometric estimation and modeling building routines in the early 1980s.

Speakeasy's extensibility capabilities exceed those of GAUSS. Users can write their own routines in FORTRAN or "C" and include them as part of Speakeasy's library. Speakeasy also contains protocols to facilitate customized menus and input screens. Separate routines are furnished to allow Speakeasy to access databases, such as DBASE.

In the last few years, Speakeasy has been transferred to a number of work stations, including Sun, Hewlett-Packard, and IBM. On IBM workstations, Speakeasy uses a highly efficient set of matrix and numerical analysis routines that have been optimized for this particular machine.

A version of Speakeasy was released for IBM-compatible microcomputers in 1984. Unfortunately, the small memory availability of these machines at the time (8086- and 80286-based) severely restricted the capability of the system to handle large problems. A new version of Speakeasy is currently under development for 386- and 486-based computers. This version is expected to be available in the summer of 1992. Currently, the price is undetermined, but based on the pricing for the previous microcomputer version, it is expected to be in the $1000 to $1500 range. Whether executable models can be distributed to non-Speakeasy users has not yet undetermined.

Speakeasy's numerical and array capabilities, combined with menu-building and graphical routines, make it a very attractive candidate for model development and dissemination. The model development process can be facilitated by the availability of Speakeasy for various work stations. This code can then be transferred to the PC.

11.3 Recommendations

The discussion above provides a brief look at some of the leading candidates in the a software environment for an enhanced commercial sector energy model. The only strong conclusion is that a spreadsheet would not be an efficient tool to use for such a model. The "C" language provides the most flexible environment, in some respects; however, it may have the highest development cost, with some question about how easily it can be modified by others the original developers. GAUSS and Speakeasy both represent high-level matrix and extensible language frameworks that are well suited to the computational requirements of a disaggregated energy model. On the more powerful microcomputers (based on the 386 and 486), these environments may provide a more cost-effective approach to long-term model development and updates than the traditional programming languages.

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