MODELS FOR RESIDENTIAL AND COMMERCIAL SECTOR ENERGY CONSERVATION ANALYSIS: APPLICATIONS, LIMITATIONS, AND FUTURE POTENTIAL

HITTMAN ASSOCIATES, INC.
9190 Red Branch Road
Columbia, Maryland 21045

HITTMAN

DISCLAIMER

MODELS FOR RESIDENTIAL-AND COMMERCIAL-SECTOR ENERGY-CONSERVATION ANALYSIS: APPLICATIONS, LIMITATIONS, AND FUTURE POTENTIAL

FINAL REPORT

H-C1011/002-80-948F

Contract No. DE-AC01-79PE70044

By:

Henry E. Cole
and
Robert E. Fullen

Submitted to:

U.S. Department of Energy
Conservation Policy Office
Washington, DC

Prepared by:

Hittman Associates, Inc.
9190 Red Branch Road
Columbia, Maryland 21045

September 1980

NOTICE

This report was prepared as an account of work sponsored by the U.S. Department of Energy. Neither the U.S. Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

ACKNOWLEDGEMENTS

This study to assess four major residential and commercial energy conservation models was performed for the Conservation Policy Office of the U.S. Department of Energy as part of the task "Review and Analysis of Residential and Commercial Sector Buildings Data and Models for Applicability to DOE Policy and Evaluation Activities." An overview of the analytical tools for this task is presented in a companion study, Major Models and Data Sources for Residential and Commercial Energy Conservation Analysis. Appreciation is extended for guidance and direction in these efforts to the DOE project coordinator, Ms. Karen Griffin, and the technical monitor, Dr. John Wilman.

Many others have made essential contributions to this study. Dr. Kathleen Hereford developed preliminary analyses for the commercial sector models. Dr. Harley Barnes authored the Appendix and provided guidance on the translation of DOE goals and objectives into conservation programs and their analytical requirements. Valuable assistance was provided by Mr. Charles Lapinski in technical and editorial review and by Ms. Dorothy Weatherby and the Hittman Associates, Inc. word processing staff in assembling, editing, and presentation of the document. The work greatly benefited from numerous discussions with the staff of DOE and the National Laboratories and various research instititions. In particular, this includes Dr. Gerald Peabody of DOE Energy Information Administration, Dr. Steven Carhart of the Mellon Institute Energy Productivity Center, Drs. Dennis O'Neill and Ken Corum of Oak Ridge National Laboratories, Dr. Jerry Jackson of Georgia Tech's Economic Development Laboratory, and Dr. Peter Kleeman of Brookhaven National Laboratories. Responsibility for the paper remains, of course, with the authors.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION AND RANKING OF MODIFICATIONS AND EXCEPTIONS

This report reviews four of the major models used by DOE for energy conservation analyses in the residential and commercial building sectors. The objective is to provide a critical analysis of how these models can serve as tools for the Department of Energy (DOE) and its Conservation Policy Office in evaluating and quantifying their policy and program requirements. For this, the study brings together information on the models' analytical structure and their strengths and limitations in policy applications. These are then employed to assess the most effective role for each model in addressing future issues of buildings energy conservation policy and analysis.

The four models covered by this report are:

- The Oak Ridge Residential Energy Model (Chapter I)
- The Micro Analysis of Transfers to Households/ Comprehensive Human Resources Data System (MATH/CHRDS) Model (Chapter II)
- The Oak Ridge Commercial Energy Model (Chapter III)
- The Brookhaven Buildings Energy Conservation Optimization Model (BECOM) (Chapter IV).

These models were selected in consultation with the Conservation Policy Office as the most prominent macroanalytical tools used in assessing the Department of Energy's residential and commercial energy conservation programs. Except for BECOM, each is in operation at DOE's Energy Information Administration (EIA). Their macro emphasis reflects the importance at the national and regional levels of understanding, planning, and implementing changes in energy use and fuel demands in the buildings sector. In order to cover most major issues and impact areas of buildings energy conservation, the four models were chosen to be complementary rather than competitive with one another in their analytical structure, sectoral detail, and policy relevance. Specifically:

- The Oak Ridge Residential Energy Model and the Oak Ridge Commercial Energy Model offer detailed simulation of energy demands by building types, end uses, and fuels for their respective sectors derived from engineering and econometric estimates.
- The MATH/CHRDS micro simulation model provides distributional energy expenditure and fuels detail of household energy consumption developed from

census and survey-derived synthetic micro household data of demographic, economic, and energy-related characteristics.

- The Brookhaven Buildings Energy Conservation Optimization Model takes as given the residential and commercial sector fuels supplies and final demands and, using a linear programming framework, selects energy-using technologies and energy flows in buildings to meet the final demands at least cost.

This study assesses the ability of the selected models to provide information that will be useful to DOE in evaluating specific initiatives targeted toward national buildings energy conservation goals and objectives. The Appendix to this report presents a structure for DOE's general conservation goals and objectives for the buildings sector and outlines the specific objectives and programs designed to achieve these within DOE policy constraints. To illustrate the application of the study, two highly ranked specific objectives indicated for both the residential and commercial sectors are the retrofit of existing buildings with energy conserving/energy efficient technologies and minimum standards for improved energy performance of new buildings. The study inquires whether the structure and application of the models can assist in the analysis of program and policy initiatives (for example, tax credits, energy audits, weatherization assistance, energy performance, and efficiency standards) to achieve these specific objectives. Where the models are found to be most suitably applied, the discussion in this report can better acquaint the potential users with the modeling resources they have on hand and can aid in selecting and drawing upon these more effectively for analyses of specific issues. Where weaknesses in the models are identified for these applications, the study suggests model modifications, reestimations, or updates that would strengthen analysis and understanding of specific building energy conservation issues and enhance the role of the models for future conservation planning.

Chapters I through IV present a separate analysis of the individual models. Each chapter is intended to stand alone, without reference to the other analyses. The discussion in each, however, follows a similar outline:

- Introduction, background, and summary of findings on applications and limitations

- Model structure, estimation techniques, data inputs and outputs

- Current capabilities for analysis of building energy conservation issues and policy applications

- Current limitations and suggested modifications to enhance the model's contribution for future buildings energy conservation policy and planning.

The analysis of each model draws on a large number of documents describing their structure, estimation, and applications, and also relevant data sources, predecessor studies, and new or contrasting approaches and estimations.* These were augmented by discussions with the model developers and users. Because the models are likely to have had numerous undocumented applications and are subject to ongoing model development at various institutions, this study may not have fully captured all aspects of their capabilities. The analysis does, however, focus on those versions in current production for DOE, since suggested changes or applications of these are most likely to affect buildings energy conservation policy development and the program implementation.

For each model, the study indicates the primary areas where modifications or extensions of the models would be useful, and the difficulties in undertaking these. Table 1 summarizes the authors' judgmental ranking of the more important of these indicated model changes for building energy conservation policy analysis. The table assigns a priority to each modification, identified by the model to be affected and the nature of the extension. Table 1 also displays the page reference for further information on the need for the extended model capabilities and the procedures which could be used to implement the change.

The priorities on Table 1 were developed considering:

- DOE goals and objectives (see Appendix)

- Importance of the modification or extension to assist DOE in analyzing policies to achieve its goals and objectives

- Likelihood of successful model modification or extension

- Level of effort required for model modification or extension.

For example, refining the discount rate inputs to the ORNL residential energy model is assigned priority level 1 because accurate discount rates are an important first step in voluntary retrofit analysis (a high-priority objective) as well as in projecting the impacts of mandatory conservation

**Summary information on a number of these models and data sources is given in the companion study Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, September 1980.*

TABLE 1. RANKING OF MODEL EXTENSIONS AND MODIFICATIONS

Priority	Model	Extension and Modifications	Page
1	ORNL Residential	Refining Discount Rate Inputs*	I-33
2	ORNL Commercial	Modeling Retrofit	III-23
3	ORNL Residential	Modeling Retrofit*	I-25
4	ORNL Commercial	Technical Improvements in the Base Case	III-41
5	ORNL Residential	Renter/Landlord/Apartment Building Analysis	I-35
6	BECOM	Increase Conservation Policy Sensitivity	IV-23
7	ORNL Residential	Solar Space and Water Heating*	I-31
8	ORNL Residential	Technical Improvements in the Base Case	I-43
9	ORNL Commercial	Operational Conservation Measures	III-25
10	ORNL Residential	Rate Structure and Load Management*	I-29
11	ORNL Commercial	Renter/Landlord Effects	III-33
12	MATH/CHRDS	Increase Conservation Policy Sensitivity	II-20
13	BECOM	Model Transferability and Accessibility*	IV-34
14	BECOM	Buildings and Owner Specific Disaggregation*	IV-22
15	ORNL Commercial	Federal Buildings	III-30
16	ORNL Commercial	State/Local/Institutional Buildings	III-32
17	MATH/CHRDS	Indirect Effects on Energy Use	II-21
18	ORNL Residential	Retrofit of Appliances	I-27
19	ORNL Residential	Operational Conservation Measures	I-28
20	ORNL Residential	Regional Improvements	I-40
21	ORNL Commercial	Regional Improvements	III-38
22	MATH/CHRDS	Ownership and Use of Appliances**	II-25
23	ORNL Residential	Utility Activities (in regional model)** (in Sample Service Areas)*	I-36
24	ORNL Commercial	Utility Activities	III-35
25	ORNL Commercial	Rate Structure and Load Management*	III-25
26	ORNL Commercial	Solar Space and Water Heating	III-27
27	MATH/CHRDS	Ownership and Use of Appliances**	II-25
28	BECOM	Multiperiod Analysis*	IV-33
29	MATH/CHRDS	Structure and Appliance Efficiency Decisions**	II-26
30	BECOM	Data and Parameter Updates*	IV-21
31	ORNL Commercial	District Heating**	III-29
32	ORNL Residential	District Heating**	I-30

*Extension involves completing or refining preliminary efforts on the model or adapting or integrating results from other models with relative ease.

**Extension involves significant model development and/or data gathering.

programs. Moreover, substantial progress has already been made in estimating the appropriate discount rates; finalizing this research and integrating it with the ORNL Residential Model should have a large benefit relative to required level of effort. In contrast, modelling retrofit in the ORNL Commercial Model (the highest-priority objective, commercial retrofit) would entail a greater level of effort but significantly improve the conservation policy analytical capability of the model.

Modifications and extensions of the ORNL Residential and Commercial models were generally more extensive and ranked above those of the BECOM and MATH/CHRDS models. This is because the former are more fully embedded as tools in the decision framework of DOE and somewhat better suited to analyzing the direct energy and economic impacts of conservation policies. The latter, on the other hand, provide more disaggregated analyses of specific technology penetrations (BECOM) or household characteristics (MATH/CHRDS), but with somewhat fewer explicit feedback mechanisms of sectoral energy demand. National extensions were ranked above regional/utility-service-area analyses due to the greater data gathering and model development efforts required to perform assessments of policies on a state and service area level. Of course, the rankings could change as other specific policy analytic requirements are defined.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

I. OAK RIDGE NATIONAL LABORATORY RESIDENTIAL ENERGY MODEL

A. Introduction

The Oak Ridge National Laboratory (ORNL) Residential Energy Model is one of the central analytical tools for planning and assessing the impact of the Department of Energy's residential energy conservation programs. This chapter discusses actual elements of the model structure, identifies its present applications and suggests future changes that will enhance its potential to address issues and program areas of importance to residential energy conservation analysis. The background and outline for this study are discussed briefly below, and the results summarized. The chapter also presents a more detailed overview of the present structure and capabilities for policy analysis. The remainder of the chapter suggests refinements and modifications that would permit the model to be extended to additional issues and programs for energy conservation in the residential sector.

1. Background

The Oak Ridge National Laboratory Residential Energy Model was developed as a long-run simulation model to predict annual, national, and regional residential fuel demand from 1970 to 2000. The purpose of the model is to assist public and private sector decision-makers in planning and evaluating the impacts of energy conservation strategies and policies. The model provides disaggregated residential energy use information on four fuels, eight end uses, three housing types, and two housing states (new and existing) at the national or regional level. Forecasts for each of these housing, fuel, and end-use combinations are determined in response to changes in households and housing stocks; equipment ownership by end use and fuel type; housing unit thermal integrity; appliance energy requirements; and usage factors that represent household energy-use decision making.* The model is thus sensitive to major demographic, economic, and technological determinants of residential energy use.

The ORNL Residential Model in its regional version provides the basis for the residential energy demand sector (Structural Residential Energy Use Model) of DOE's Energy Information Administration (EIA) Midterm Energy Forecasting System (MEFS). The model also is used extensively for analysis

**The terms appliances and equipment are used interchangeably in this report.*

and evaluation of DOE residential energy conservation programs and of proposed conservation policies, including standards for appliance energy efficiencies and buildings thermal performance, fuels pricing, conservation investment tax and loan incentives, direct government grants and assistance, and promotion of research and new conservation technologies. A state-level version of the model was developed to respond to planning and implementation needs for state conservation programs, but this has not yet been fully applied as an energy conservation planning tool.

Both the structure and application of the model have been developed in a series of ORNL studies over the last decade. These studies investigated various engineering and economic aspects of residential energy consumption and were integrated to form the basis for the model. The work is ongoing, but the basic description of the present model is documented in Hirst and Carney, 1978, The ORNL Engineering-Economic Model of Residential Energy Use. Applications of the model to residential energy conservation issues are numerous; Hirst and Carney, 1977, Residential Energy Use to the Year 2000: Conservation and Economics provides a summary of the results for many of the major conservation issues.*

The ORNL documents, together with study of the computer programs, conversations with ORNL scientists, EIA and DOE planning and program staff, and discussions with other users of the model, form the basis for the analysis that follows.

2. Outline and Scope of the Study

Both in its use by EIA for energy forecasting and in its applications within DOE and at ORNL for conservation program planning and policy development, the ORNL Residential Energy Model has proved a valuable tool for analysis of a wide variety of energy conservation programs. At the model's current state of development, however, there are limitations on the types of conservation programs that may be simulated. Also, the model's base-case forecast has the potential to be improved by refining input data and some of the model's algorithms. This chapter reviews several areas of residential energy conservation analysis to which the model may be applied and suggests extension, modifications, and data that may

**Additional summary information on the model structure, policy variables, inputs, outputs, data sources, specific versions, and accessibility are introduced in a companion publication Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, Hittman Associates, Inc., June 1980.*

strengthen and broaden these applications. These are intended to alert policy makers and planners to the model's capabilities and to provide information to support future residential energy conservation analyses. The results of this are summarized before the next section.

The major sections that follow present the more detailed context for these findings. Section B provides an overview of the model structure and introduces the major variable and analytical elements of the model. This is suffiently detailed to provide a reference for the later discussion and to identify the primary source documents. For the reader who is well acquainted with the ORNL Residential Energy Model, this section may be omitted. The current major policy analysis applications of the ORNL Residential Energy Model are outlined in Section C. These are introduced both to alert the user to the present model potential and to provide the basis for understanding what more could be done. Section D then indicates extensions of the model that would enhance the model's potential to address additional residential energy conservation issues and to increase the precision of several existing applications. This discussion attempts to relate these directly to the model's analytical structure and data and to suggest modifications, additional research, and data to alleviate any difficulties.

3. Summary of Findings

a. Current Application of the ORNL Residential Energy Model. The ORNL Residential Energy Model has been applied to at least six major areas of energy conservation analysis. These are:

(1) Standards for Improved Energy Performance of New Residential Buildings. The model accepts ratio increases in thermal integrity of new buildings estimated to occur through standards mandating more energy-efficient building design and materials. Materials and installation costs for these steps are calculated in the model and can be compared to the simulated changes in fuels demand for heating and cooling by housing type and end use.

(2) Standards for Energy Efficiency in New Household Appliances. In a similar fashion, the model accepts input ratios of new appliance energy use relative to 1970. The model simulates the resulting reductions in residential energy consumption and the necessary appliance investment costs.

(3) Retrofits of Existing Residential Buildings. Estimates of the numbers and types of housing units and their energy use reductions due to weatherization programs and incentives are input to the model. These are calculated outside the model as the estimated results of tax and loan incentives, increased conservation information and awareness, and utility assistance programs. The model simulates the overall saving in residential energy use and compares this to the model-calculated or federally budgeted investment costs.

(4) Conservation Technology Research and Development. Estimated increases in building or equipment energy use efficiencies and/or the reduction in their costs due to research and development support can be used to alter resident's choice of designs, materials, or appliances for new structures. These shift the coefficient of the capital cost versus operating cost technology trade-offs available to the consumer for cost-effective investment decisions. Energy savings and new investment costs are calculated by comparing the results to simulation without the new technologies.

(5) Grants and Subsidies and Low-Interest Loans. Effects of tax incentives or equipment, materials, and installation subsidies are expressed as modifications in the conservation technology costs for new buildings and equipment. The lowered capital costs permit purchases of normally more expensive equipment with lower operating costs.

Low-interest loans are simulated as lowered interest rates used in the consumer's cost-effective investment criteria for new residences and their equipment. Lowered rates enhance the present value of reduced operating costs from more efficient equipment.

(6) Energy Prices. The impacts of increases in fuel costs are captured in the model by three effects:

(a) Higher prices of one fuel reduce that fuel's market share in new appliance choices.

(b) Higher relative prices of one fuel or higher absolute prices for all fuels lead to choices of more energy-efficient new appliances and structures.

(c) Higher prices reduce equipment usage.

b. Extensions and Modifications of the ORNL Residential Energy Model for Energy Conservation Analyses. Although current versions of the ORNL Residential Model are applicable to a broad range of energy conservation topics, as evidenced above, the findings indicate that the model's use could be enhanced in several areas. Extensions of the model through various modifications of the structure and by reestimations from new data sources could further increase the model's potential to assist policy planning and evaluation of residential energy conservation.

The following 11 topic areas were selected, given the model's basic capabilities, as areas where extensions, modifications, and applications of the model would be of significance to DOE objectives for future residential energy conservation planning and policy analyses. (See the Appendix to this report for a discussion and outline of these DOE objectives.) The topics embody both refinements in the existing model structure and substantial modifications that would permit the user to better address key conservation issues and policy variables. (In many cases, however, the refinement or modification can only suggest a possible direction for further work.) A brief outline of the proposed applications and suggested changes are given below. Additional details and justification for these are given in Section D of the text.

(1) Retrofit of Existing Residences for Better Thermal Performance. The current model is adequate where the number of residences expected to be retrofitted and the changes in thermal performance for each retrofit program are estimated and provided as inputs to the model. More explicit modeling of the retrofit decision could be important to simulate the effects of ongoing incentives to retrofit embodied, for example, in tax rates, fuel prices, and changing technologies. A modification is suggested to divide housing into separate fractions where characteristics support their applicability to retrofit.

(2) Retrofit of Existing Appliances for Better Efficiency. The model does not currently simulate retrofit appliance conservation programs as the model appliance efficiency standards apply only to new buildings. A first step to modify this would be to follow the same procedure currently used for retrofitting thermal performance. The numbers expected to be retrofit, efficiency changes, and purchase prices would be input to the model. Further modifications would

require explicitly modeling early retirement of "inefficient" appliances..

(3) Operational Conservation Measures. The model simulates the effects of changing energy prices on usage (operation) of equipment. However, the effects of programs that directly restrict usage, such as thermostat setbacks or lighting standards, are not explicitly modeled. To modify this, the computer code could be reprogrammed to accept a maximum usage for each affected end use. This maximum would be the engineering estimate of the change in energy used due to the operational change. (For example, 1°F cutback in the thermostat might reduce heating energy use by 5 percent.)

(4) Rate Structure and Load Management. The model accepts average annual fuel prices and cannot be used to evaluate the impacts of rate structure policies. Similarly, since the model only calculates annual energy use, it cannot be used for evaluation of load management programs. Modifications to incorporate these effects would be extremely difficult. Modification of the model to accept different rates for different appliances provides a partial solution for some recent rate changes.

(5) Alternative Energy Supplies - District Heating. The model calculates consumption of electricity, natural gas, fuel oil, and other (primarily propane). It does not currently simulate the use of steam for district heating (used primarily in large apartment complexes). To explicitly treat this in the model: market shares of space heating fuels need to be modified to include the fraction of residences where this is available; the market share elasticities would need to be developed; the model would need to be modified to accept prices for steam; and a technology characterization would have to be added. Presently, data for these are few or location specific and modeling even at the regional level would only be a weak approximation.

(6) Alternative Energy Supplies - Solar Space and Water Heating. These are not represented in the current model. With appropriate data, the technology characterization function could be modified to accept these options, though the results would show only the energy used in the backup fuel. Much of the data for this currently exist in solar market development and penetration models sponsored by DOE.

(7) Consumer Behavior and Choice of More Efficient Equipment; the Discount Rate and Market Penetration. Estimates of the way that consumers discount future energy savings versus equipment costs in choosing equipment efficiencies are imprecise and based on weak analytical and empirical grounds. The "implicit discount rate" embodies consumers' subjective rate of time preference toward energy conservation investments and also the market imperfections that may not permit the consumer to choose the most cost-effective conservation investments. Lack of a better specification of these affects simulation of the impacts of consumer information programs and of financing incentives, among others. Ongoing research on the "implicit" discount rate and overall fuel choice should provide improvements in this area.

(8) Renter/Landlord/Apartment Building Analysis. The model presents energy use by building type, but not by ownership or billing characteristics. Since household incentives to conserve energy appear to differ by ownership and billing, programs to affect these cannot be directly modeled. However, there is a moderately good correlation between building type and ownership and billing. A modification of the model to allow the "implicit discount rate" (a partial proxy for the consumers' subjective valuation of future savings) to vary across building types might capture these effects.

(9) Utility Activities. Many energy conservation activities mandated or voluntarily undertaken by utilities are only partially amenable to analysis with the present model structure. These include: energy audits and public information programs, changing rate structures, low-interest loans and provision of low-cost conservation equipment, energy conservation standards, alternative energy sources, and load management. More explicit modeling of most of these is summarized in points 1 through 8 above. In some cases, additional modifications would need to incorporate fractional effects related to specific utility service areas or would require modeling at the utility level.

(10) Regional Energy Use and Conservation Activities. The ORNL model has been disaggregated to make regional projections at the federal, regional, and state levels. These rely on a mixture of elements from the national model structure and data inputs from the specific regions. Improvements needed to more accurately differentiate regional responses and impacts include: estimates of technology coefficients (efficiency versus capital cost) for individual structures and

appliances that differ by region; and estimates of the fuel market shares responses to price change elasticities as these differ by region. Though a state-level version of the model has been developed and state-level information found important to the planning and progress of various conservation efforts, this state-level version has not been actively applied at EIA or elsewhere.

(11) Technical Improvements in the Structure of the Base Case of the ORNL Model. Specification of the model's base case could be improved by refining some of the coefficient estimates and input data. These include: (a) update of the market share elasticity coefficients; (b) empirical verification and update of the usage (operational) elasticities that are based on engineering judgments; (c) reconciliation of the disaggregated elasticities of fuel market shares, equipment ownership and usage with the overall fuel use elasticity estimates; (d) reformulation of the appliance decay rates to fit a more realistic replacement pattern; and (e) disaggregation of end-use energy consumption to give more information reflecting differences in energy conservation decision making among building types and new and replacement markets.

B. Overview of the Model Structure

The ORNL Residential Model employs a capital stock approach to energy consumption. This approach recognizes that energy is consumed by capital goods (housing and appliances) to provide the more direct energy-using services desired by the household sector. Energy demand thus varies by changes in the stocks of energy-consuming capital, and by the utilization level of those stocks. To estimate and implement this structure, the model combines demographic, economic, and technological variables specific to the residential sector. The demographic analysis projects household formation and housing stock depreciation to estimate housing stock and new additions. The economic analysis develops fuel price, equipment price, and usage elasticities for appliance ownership and energy use decisions. The technological variables permit analysis of the engineering trade-offs of energy use and efficiency to capital costs for heating and cooling equipment and their efficiencies.

The analysis relies heavily on both economic and engineering relationships to calculate future energy demand. Econometrically estimated equations describe short-run energy utilization responses due to changes in, for example, fuel prices. Similarly, fuel choice or fuel switching is primarily forecast with econometric models. Engineering relationships are a key to purchaser and consumer decisions affecting future equipment efficiencies, as well as technology descriptions and cost analyses.

Figure I-1 presents a schematic of the ORNL Residential Energy Model. The characteristics of the housing stock and new construction determine the number of residential energy consumers and the share of new buildings in the stock. Fuel and equipment prices, income, and input elasticities (response of a variable in the model to another variable) determine the appliance choices, by fuel type, for new homes and the operation of appliances. Energy use/initial cost relationships as well as building and appliance efficiency standards inputs determine the efficiency of new appliances and thermal integrity of new buildings. The model computes residential energy consumption by fuel type, as well as the capital cost of energy-using equipment.

The discussion below describes briefly the three major parts of the model structure: the housing or demographic analysis for housing stock, the technology analysis of equipment or housing structure energy efficiency versus capital costs, and the economic analysis of household responses to changes in fuel prices.

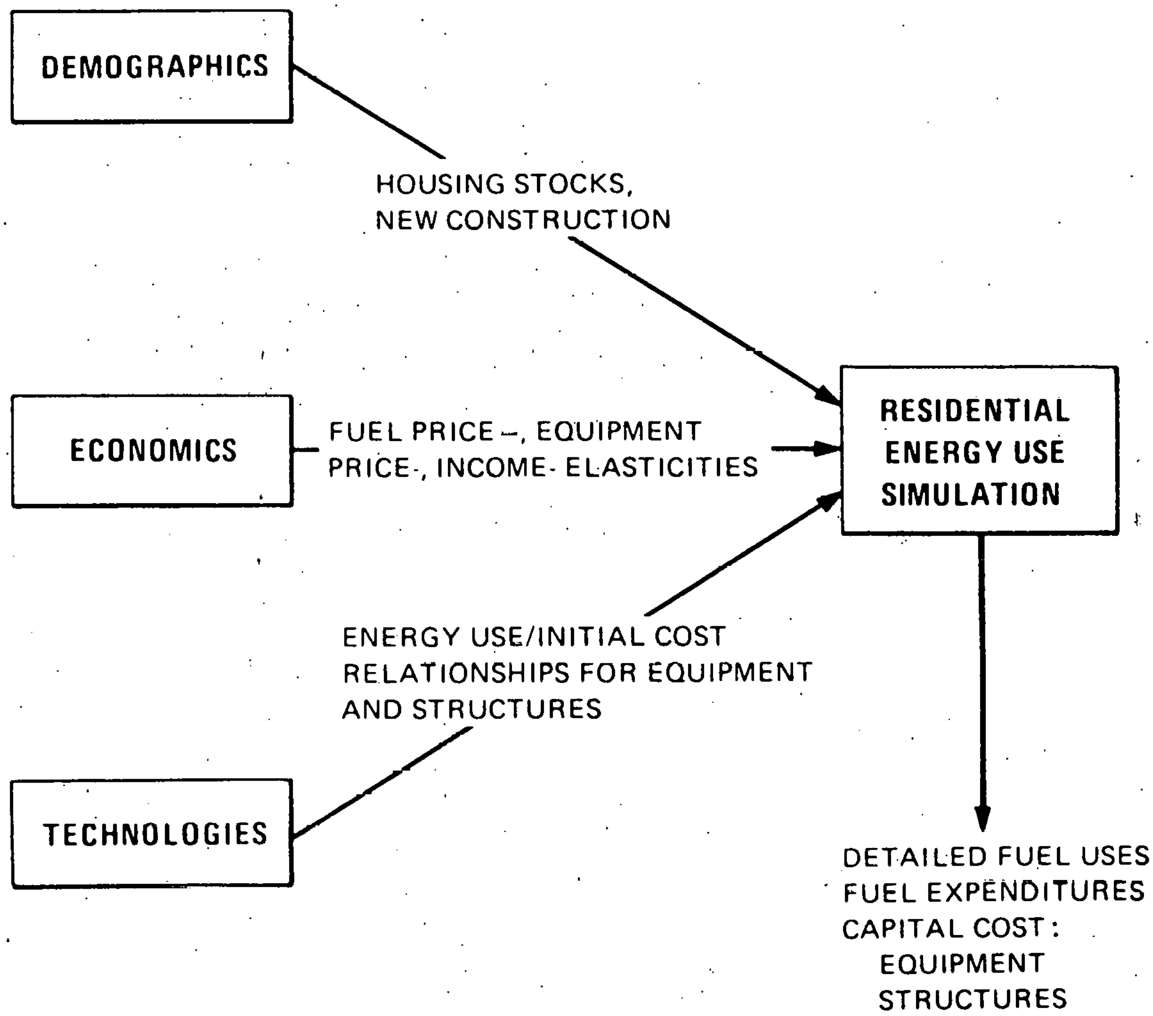
1. Housing

The housing model generates forecasts of occupied housing stock and construction of new housing for each year. The analysis rests on population, household formation, housing preference, and on retirement rates of structures. Projection of the number of households is determined by econometric estimates of household headship for each of seven age groups as a function of age, family income, marital status, and previous year households, in the form:

$$\ln\left(\frac{HR_i}{U_i - HR_i}\right) = A_i + B_i Y_{it} + C_i SD_{it} + D_i M_{it} + E_i \ln\left(\frac{HR_i}{U_i - HR_1}\right)_{t-1},$$

Where:

i = the age group
t = the time period
A,B,C, D,E = regression coefficients
HR = headship rate
U = upper limit



Source: Eric Hirst, et al., "An Improved Engineering-Economic Model of Residential Energy Use," Oak Ridge National Laboratory, February 1977, ORNL/CON-8

Figure I-1. Schematic of ORNL Residential Energy Use Model

M = fraction married
SD = fraction separated or divorced
Y = median family income.

The stock of occupied housing units is assumed equal to the number of households. The distribution of housing type across these is determined from historical and trend data for housing choice by age. Calculation of new housing units constructed is based on additional housing requirements above previous-year stocks and the necessary replacements for retirement of existing units. The most recent versions (Versions 6 and the soon-to-be-completed Version 7) of the model also accept stocks and new construction of occupied housing units as an annual input projection.* (See Hirst and Carney, 1978, p. 11 for additional details.)

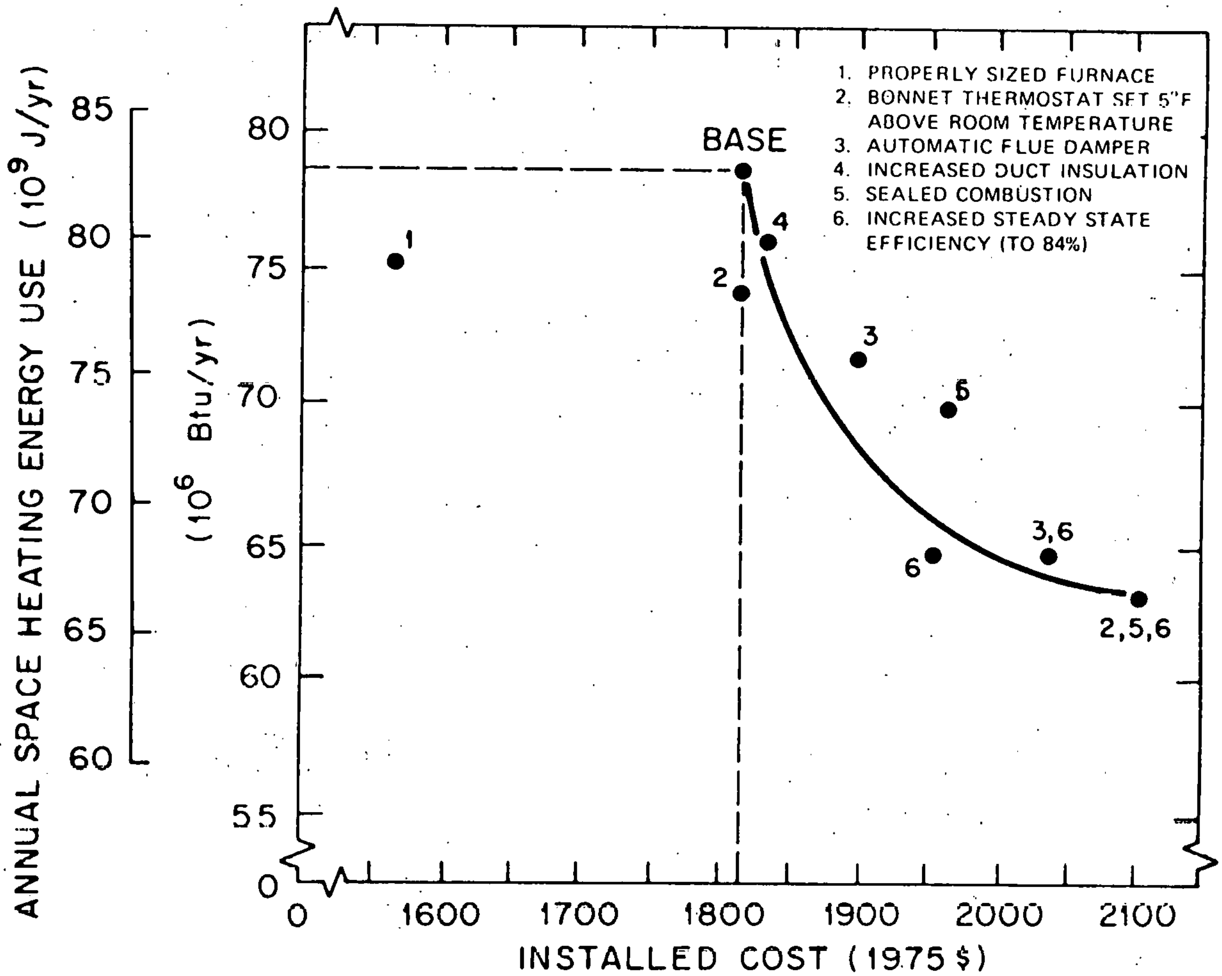
2. Technology

The technology model provides analysis of trade-offs between energy use of new equipment or structures (i.e., their efficiencies) and their capital costs. This basically entails minimum life-cycle cost calculations comparing operating costs to initial costs for equipment or building designs. Changes in equipment/appliance efficiencies determine fuel savings which are later discounted to the present to be compared with increased equipment costs. This analysis is provides for improvements in thermal performance of the three housing structure types for winter heat loss and summer cooling gain and for appliance and equipment efficiencies of electric, gas, and oil space heat; electric water heaters; refrigerators; and air conditioners.

Detailed engineering and cost analyses have been undertaken by ORNL for each appliance and housing type. The results for each are approximated in engineering curves that relate the equipment energy use requirements to the capital cost of the equipment and/or the housing shell installations. Figure I-2 is an example for space heating. The resulting equation for heating energy use could be given as:

$$C = \frac{a - \ln (E - b)}{d}$$

The term "model version" is used in two senses. First, as used above, there are several structural "versions," which are basically refinements and data updates of the model structure given in Hirst and Carney, 1978 (Versions 5, 6, and 7). Second, there are regional "versions" that apply this same model structure to individual regions or states.



Source: Dennis L. O'Neal, "Energy and Cost Analysis of Residential Heating Systems," Oak Ridge National Laboratory, 1978, ONRL/CON-25, p. 6.

Figure I-2. Annual Space Heating Energy Use Vs. Installed Cost for Design Changes in an Oil Heating System in Philadelphia

Where: C = capital cost relative to a base year
E = equipment energy use requirements relative to a base year
a,b = parameters related to asymptotic limits in use due to improvement and to the base case
d = parameter of the curve.

Relating these results to the corresponding operating costs yields the life-cycle cost equations.

3. Economics

The economic model analyzes household energy demand responses to fuel price changes. Changes in the overall consumption of a fuel are presented as the result of short-run adjustments in equipment usage levels and of long-run changes in the type (fuel switching) and in the quality (increased efficiency) of the energy-using equipment or structure. A distinctive and important feature of the model is that analysis of energy demand responses to fuel price changes is represented explicitly in three elements: equipment market share elasticities (Ems), equipment usage elasticities (Eu), and technical efficiency elasticities (Ee).

$$E = Ems + Eu + Ee$$

These are discussed briefly below.

(a) Equipment Fuel Choice or Market Share Elasticities With Respect to Fuel Price. These estimate the changes in fuel consumption due to changes in fuel choice for new and replacement units (e.g., from electric to gas hot water heaters). These elasticities are econometrically estimated for five major end uses as a function of fuel prices, equipment prices, per capita income, temperature indices (for space heating and cooling), percentage of all households in single-family units (food freezers), and percentage of households living in urban areas (food freezers). Estimates were developed using the techiques of conditional logit analysis. $S_i/1-S_i$ was estimated for the variables listed above using state-level data, where S_i is the fraction using fuel i for the selected end use. (See Lin, Hirst and Cohn, 1976, p. 6ff for further details.)

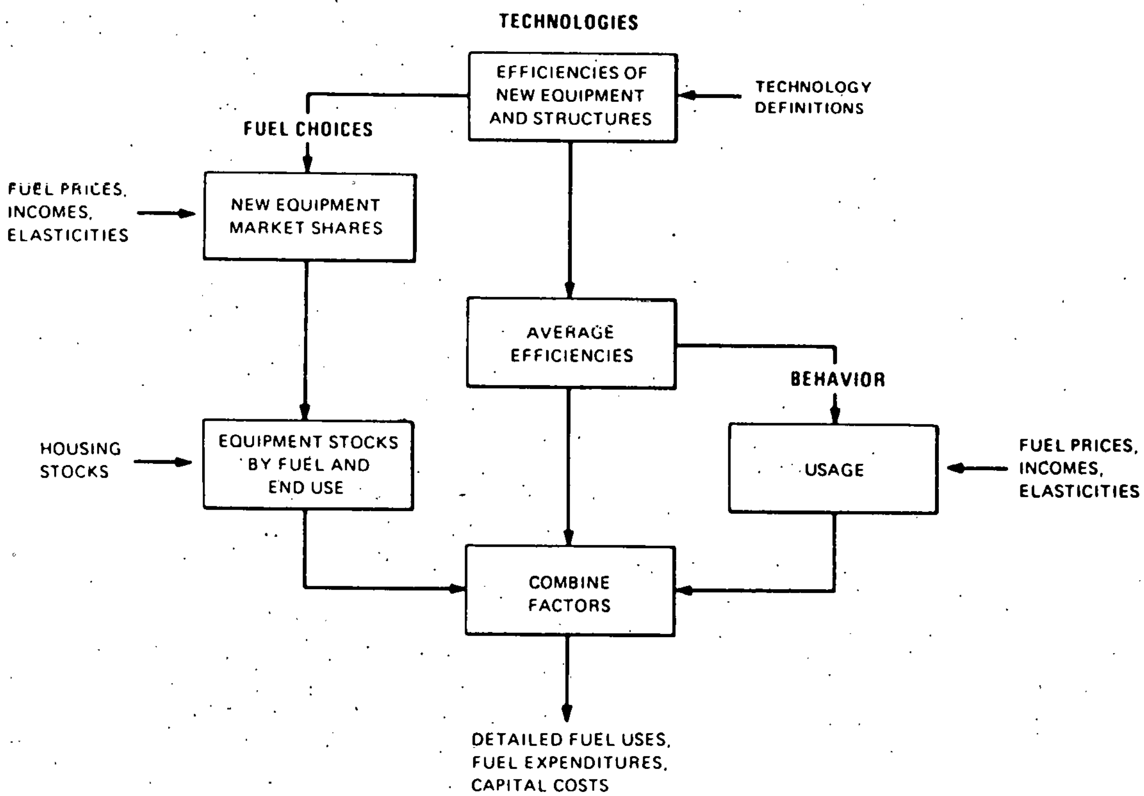
Market shares of new equipment and their responsiveness with respect to changes in the sales prices of that equipment can also be estimated by "levelizing" the equipment capital cost over the equipment lifetime (using the appropriate implicit return on that investment as the interest rate) and then relating this to the fuel price market share elasticity estimates (see Hirst and Carney, 1978, p. 33 for further details).

(b) Equipment Usage Elasticities with Respect to Fuel Price. These indicate changes that may occur in the operation of the appliance, equipment, or housing structure, assuming the equipment or housing structure remains unchanged (e.g., changes in house temperature settings, or in clothes washing practices). These elasticities are based on estimated engineering possibilities (as opposed to econometric estimates derived for other energy demand models) of what actions could be undertaken by households. Short-term versus long-term effects are determined by inputs that suggest that one-half of the total usage response occurs during the first year.

(c) Technical Efficiency Elasticities. These elasticities represent changes in purchase decisions by residents concerning the efficiency of their energy-using equipment or thermal performance of new structures as fuel prices change (e.g., shifts from electric resistance heating to electric heat pumps or shifts to better insulated housing). The decision is a dynamic one: For structural efficiency (thermal performance, for example), the technology analysis discussed in (B2) above provides the trade-offs between energy use (efficiency) and the capital costs. These trade-offs vary as fuel prices shift. Ideally the consumer would choose equipment (and efficiency) at the minimum life-cycle cost for a given fuel price. Empirical evidence indicates that the consumer does not purchase at the minimum cost point because of market imperfections. For market penetration, the model postulates that as fuel prices increase, this distortion declines. For new, more efficient equipment and their market penetrations, the results are similar except that the interest rate used by consumers in comparing operating cost savings to capital cost is first estimated via econometric estimates of new equipment market shares. (See Hirst and Carney, 1977, p. 45ff, and Hirst and Carney, 1978, p. 37ff, for a graphic treatment of this approach.)

4. Simulations

The simulation model combines the outputs from the various demographic, economic, and technology submodels together with the initial and end-value conditions (e.g., market shares, fuel, and equipment prices) to calculate the household demand forecasts by fuel and end use. Figure I-3 illustrates how the inputs and various submodels operate for simulations.



Source: Hirst and Carney, 1978, p. 45, ORNL DWG 76 26390R

Figure I-3. Flow Diagram for ORNL Simulation Model

ORNL describes the basic equation of the simulation model that defines residential use of fuel i for end use k in housing type m during year t as:

$$Q_t^{ikm} = HT_t^m \, HS_t^m \, C_t^{ikm} \, TI_t^{ikm} \, EU_t^{ikm} \, U_t^{ik},$$

Where

> HT is the stock of occupied housing units, HS is the average size of housing units (for space heating and air conditioning only), C is the fraction (market share) of households with a particular type of equipment and fuel, TI is the thermal performance of housing units (for space heating and air conditioning only), EU is the average annual energy use for the type of equipment, and U is a usage factor. (Hirst and Carney, 1978, p. 46).

In this simulation equation, housing stock and size are straightforward applications of the housing model discussed earlier. The fraction of households of a particular housing type, fuel, and end use (C_t^{ikm}), is determined from the fraction remaining from the previous year plus the fraction of new equipment going to that particular housing-fuel-end use. This latter is derived by using appropriate estimates of market share elasticity parameters and applying these to given fuel and equipment prices, housing thermal performance, and new equipment energy use. Average annual energy use (EU_t^{ikm}) is calculated from the previous year's energy use and the new equipment energy use from the technology-efficiency analysis, appropriate discount rates, and the market penetration. The usage factor U_t^{ik} is derived from the equipment-fuel usage elasticities.

The simulation model projects estimates of national (or regional) energy use for the period 1970 to 2000 using 1970 (and in some recent versions, 1977) initial condition as input for fuel prices, housing stocks, market shares, equipment fuel use, equipment prices, and new equipment installed. These are combined with expected conditions from 1980 through 2000 for fuel prices and incomes, and the array of potential changes in equipment and in housing structures due to energy conservation programs or expected future technology developments. These include, for instance, performance standards for new equipment and for thermal characteristics of new and existing structures and also new technology developments from energy research and development. The results provide detailed estimates of energy use by fuel, end use, and housing, and the intermediate estimates of installation and ownership of new equipment, the changes and costs in improved thermal performance, and the expenditures on fuels and equipment.

5. Policy Variables and Parameters

Residential energy conservation policy and program analysis is enhanced by several features of the ORNL model: the level of disaggregation, the engineering economics detail, and the fuel price elasticity components analysis. The body of the report discusses more specific applications of these policy variables to energy conservation analyses.

a. Level of Disaggregation. The large number of end uses (8), fuel types (4), building structures (3), housing states (2), and regions (10) permits more precise and targeted specification of policy inputs and more detailed evaluation of policy impact than previous residential sector models.

b. Engineering Data, Cost Analyses, and Structural Model Relationships. The engineering representations of equipment efficiencies and energy use characteristics permit simulation with changed efficiencies, technology cost-efficiency curves, or utilization rates for existing or new equipment and structures.

c. Fuel Demand Elasticities of Equipment Fuel Choice, Usage, and Technical Efficiency. These disaggregated elasticities present an analytical and simulation structure that represents consumer responses more accurately than in previous models -- that is, it recognizes that energy demand is, in reality, demand for the end-use services provided by the energy (warmth from space heating, dried clothes, etc.), and that consumer decisions are based on the total operating price to them for providing that service. Total operating price is determined by both the fuel price and the equipment efficiency of the energy-using equipment. Over the longer run where equipment efficiencies may be altered by purchase or replacement, both fuel choice and the levels of fuel utilization are determined for each consumer by the combinations of the fuel price and equipment efficiency levels. Pricing policies, or proposed programs that affect equipment efficiency levels or building thermal performance, are more amenable to analysis, interpretation, and change through the model's explicit breakout of these interactions.

Policy and program variables that can be analyzed with the model include the following:

(1) Fuel price changes from credits, taxes, subsidies, or regulatory policies -- affecting absolute fuel price level or the relative prices between fuels. Short-term price effects are generally limited to usage effects. A longer time period allows the introduction of new equipment or building structures in accordance with cost-effective decisions on

equipment fuel choice for new and replacement units.

(2) Prices of equipment or structures, as these are affected by tax credits and subsidies.

(3) Equipment efficiency or building thermal performances, as these are affected by appliance or building standards or possibly large-scale retrofit programs.

(4) Usage factors such as building temperature controls, hot water usage, and lighting practices.

(5) Technological changes that might be introduced by innovation and research incentives. These would affect the cost-efficiency trade-off.

These policy and program variables are addressed in more detail in Section C below.

C. Current Policy Analysis Applications

1. Minimum Standards for Improved Energy Performance of New Residential Buildings

The Oak Ridge National Laboratory (ORNL) Residential Energy Model is used to compute the impact of building energy performance standards on energy use for space heating and for space cooling. The model accepts as an input the mandated thermal integrities for each of the three types of new structures relative to 1970 values. The inputs are annual* ratios of thermal integrity (TIN) by building type for space heating and for space cooling. Residential energy use is reduced by the building energy performance standards as a result of lower energy use for space heating and space cooling in new buildings. The reduction in energy use, however, is not proportional to the increase in thermal performance, since the lowered costs of achieving a given end-use energy service** (e.g., warmth) may encourage consumer choice of higher heating (or lower cooling) temperatures or increased use of other energy-using appliances.

**Version 6 of the model accepts annual inputs through 1985, then accepts inputs in five-year intervals. Intervening years are linearly interpolated.*

***The term "end-use service" is meant to indicate the final product of the energy-using device (e.g., dried clothes or a desired house temperature).*

The model assumes that space heating and space cooling demands are proportional to thermal integrity. For example, if unit space heat demand in 1970 were 100 million Btu per year and the thermal integrity ratio TIN is .55 in 1980, then a new house built in 1980 would have a space heat demand of 55 million Btu per year, other things being equal.

The model permits three options for estimating the thermal integrity of new structures:

(a) An unconstrained "cost-effective" decision is determined using the technology relationships and the interest rates relevant for buildings to calculate the minimum life cycle of thermal integrity options for each set of fuel prices and installation charges. Consumers are observed not to purchase this cost-effective minimum. A gap exists between actual and optimal (least-cost) levels of purchases. The model assumes that such a gap continues in new investment decisions to increase levels of thermal integrity; the model's penetration function, however, postulates a reduction in this gap as fuel prices rise.

(b) Alternatively, for a set of imposed buildings energy performance standards, the model compares the standards with model-determined cost-effective levels and selects those which will lower energy use. In this case it is possible that consumer behavior and advances in technology incorporated in the model are capable of surpassing some of the standards.

(c) In the third case, the standards alone determine thermal integrity.

The actual numbers of new homes to which the standards are applied are determined within the housing submodel by levels of replacement and new household formation.

2. Minimum Energy-Efficiency Standards and Targets for Appliances

The ORNL Residential Energy Model computes the impacts of appliance efficiency standards in a similar fashion to the computation of the impacts of building energy performance standards. The model accepts annual input ratios of new appliance energy use relative to 1970 use (EUN). Residential energy consumption is reduced as new and replacement appliances use less energy than existing appliances. Again, as with thermal performance standards discussed above, the precise level of consumption is determined by the consumers' response to the lower costs of the final services delivered by the more efficient appliances.

The "real" interest rates at which consumers evaluate energy savings may differ by appliance. Using this, together with the appliance and fuel costs, the consumer investment is calculated based on the life-cycle cost-minimizing choice. This is adjusted to the actual purchase level by the observed gap between the actual and cost-effective purchases. The model's market penetration function reduces this gap as fuel prices rise.

The model has five options for computing appliance efficiency for each end use:

(a) Choose the minimum energy use decision, comparing the input standards (EUN) with calculated values

(b) Accept inputs of the EUN and the equipment prices

(c) Accept the EUN input but compute the corresponding equipment prices

(d) Calculate internally the efficiency and capital cost choices without efficiency standards

(e) Calculate the minimum life-cycle cost responses without gap between minimum and actual.

The appliance standards may be the same or different for single-family units, multifamily units, and mobile homes.

3. Retrofits, Energy Audits, and Changes in Selected Energy-Conserving/Energy-Efficient Technologies in Existing Residential Buildings

The ORNL Residential Energy Model method to analyze the impacts of retrofit programs is essentially the same for all. The range of programs include financial assistance to low-income and other households to weatherize their structures, energy audits by utilities to encourage retrofits, measures such as tax credits for upgrading the structure, or other utility assistance to customers. The computation is basically the same as that for new buildings thermal performance, except that in the retrofit case specified numbers of existing buildings have their thermal performance levels upgraded.

The model requires as inputs the number of annual units by building type required or expected to be retrofit. Several options exist, depending on the design and analysis required of the planned conservation program. These include:

(a) The number of retrofits and the ratio of improvement in thermal integrity over the retrofit period for space heat. This is translatable into the TIN value for new buildings (see B.1. above); the model then computes the coincidental increase in air conditioning thermal integrity, and the unit cost of retrofit, as well as the values of residential energy use and the resulting savings.

(b) The number of retrofits, the thermal integrity improvement ratios for space heat and air conditioning, and the unit costs are inputs. The impact on residential energy use is then simulated and the savings calculated.

By allowing the installation costs to be either calculated internal to the model or given as inputs, the total investment costs can be computed under various assumptions and compared to the energy cost savings. For example, for a low-income weatherization program, having the same number of retrofits, the installation and materials costs budgeted for federal programs (including effects of tax credits or subsidies) can be compared to the investment costs that the technical submodel calculates for the specified increase in the housing thermal performance.

4. Conservation Technology Research and Development

The ORNL Residential Energy Model inputs include technology model coefficients discussed earlier which relate appliance and thermal integrity capital cost to annual energy use (efficiency). Energy use may be reduced by conservation investments that purchase more efficient (and usually more expensive) appliances. Research and development can lead to introduction of technologies that are more efficient than existing ones at the same cost and thus can reduce the cost of saving energy. Alternatively, R&D can simply increase the opportunity set of capital cost-efficiency trade-offs, but in different fuel or building type configurations.

Analysis of the effect of such technological innovations is calculated in the ORNL model by revising the technology-capital cost coefficients of the technology model to reflect the availability of the new technology after a given year (e.g., gas-fired heat pumps in single-family homes after 1985).

The effects of such innovations are seen in a change in the consumer's efficiency-capital cost choice for a given appliance. By lowering the net operating costs for those energy services, this will affect the amount of fuel consumed for a given end-use service, and perhaps increase the end-use service demand. The changes can be evaluated for the simulation results comparing energy use, fuels demands, fuel and energy savings, and the distributions by fuels-end-use-housing types.

5. Subsidy Programs

The ORNL Residential Energy Model has several inputs that may be changed to reflect incentive or subsidy programs. Subsidies for conservation efforts, such as tax credits, vendor rebates, loan market incentives, and taxes on inefficient energy use, can be reflected in the technology models; which relate energy use and efficiency to equipment costs or thermal performance installation costs. The subsidies or taxes can be expressed as modifications of equipment costs, implying revised cost coefficients for the technology. As with R&D, the subsidy programs can begin in a specified input year, and can be linked by housing and fuel as well as the specific end use.

Low- or no-interest loans for conservation can either be reflected in the technology model capital costs for equipment or installation, or in the interest rates used to determine the consumer's cost-effectiveness criteria (life-cycle cost) for conservation investments. However, the interest rates apply for the entire modeling period, as if the loans were available at the beginning of the model's time horizon.

6. Operational Factors

The ORNL Residential Model explicitly treats the effect of price and income changes in potential consumer operational changes such as setbacks in winter temperature, summer temperature settings, water heating temperature reductions, and reduced lighting. These are modeled in terms of price and income elasticities of the intensity with which households use their existing equipment. The estimates are based primarily on engineering possibilities (e.g., the effects of a 1°F setback on energy use in a house) and ORNL judgments of the relevant responses for various end uses (e.g., the opportunities to reduce energy use and save energy from an existing refrigerator are less than those from temperature changes and use of an existing hot water heater).

The model simulates the change in usage from a change in actual energy prices or from indirect price effects of incentives (or penalties). The model tends to show that the net effect of these is larger in the short run than the long run. Over the long run, the short-run incentives to change use patterns are altered by shifts to new fuels and by equipment purchases and structural improvements that alter the efficiency levels and permit higher use per operating dollar. Thus, the price variable in the usage equation could be interpreted as an efficiency-weighted fuel price. Over the long run, that efficiency will also change if prices rise.

7. Modification of Energy Prices

Changes in energy price levels and the relative prices of various fuels are most prominent in the ORNL model analysis of residential-sector energy demand. Analysis of the effects of higher energy prices has been discussed in Sections B.3. and B.5. of this chapter. Briefly this is summarized as follows: First, higher prices of one fuel reduce that fuel's market share in appliance choices for new equipment. Second, higher energy prices for that fuel, and for all fuels, lead to a choice of more efficient new appliances and structures. Third, the higher prices reduce equipment usage.

Programs that change the price of energy to residential customers can be analyzed by changing the energy price forecasts which are input to the model. Analysis of the effects of these on total energy and fuel use need to take into account uses where, for instance, new or replacement equipment has been installed, since, for the consumer, the relevant price variable is price of delivery of the end-use service. The model presents the price effects as they are weighted by their impact on end-use efficiencies; shifts to new appliances and fuels and changes in housing thermal performance are integral to the model's fuel price impacts.

D. Extending the ORNL Energy Model for Energy Conservation Analysis

Current versions of the ORNL Residential Energy Model, although applicable to a broad range of energy conservation programs, could be enhanced by reducing several limitations on the types or precision of analysis of conservation programs that can be simulated. The following discussion will consider both extensions of the model to better address key conservation issues or variables, and refinements of the inputs, coefficients, and model algorithm that would improve the basic forecasts. These are presented in the context of possible ways of modifying the model or incorporating them into the model structure.

The topics were selected, after discussion with DOE, on the basis of the value of the model changes to DOE residential energy conservation program objectives. (See the Appendix to this report for a discussion of these objectives.) The 11 topics are not intended to represent all major areas where the model could be enhanced. They are, however, priority areas of significance for application of the model for future residential energy conservation planning and policy analysis.

(1) Retrofit of existing residences for better thermal performance

(2) Retrofit of existing appliances for better efficiency

(3) Operational conservation measures

(4) Rate structure and load management

(5) Alternative energy supplies - district heating

(6) Alternative energy supplies - solar space and water heating

(7) Consumer behavior toward the choice of more efficient equipment: discount rates and market penetration

(8) Renter/landlord/apartment building analysis

(9) Utility activities

(10) Regional programs and impacts of energy use and conservation activities

- (a) Technology coefficients
- (b) Elasticity coefficients
- (c) State-level analysis

(11) Technical improvements in the structure of the base case of the ORNL model

- (a) Market-share elasticities
- (b) Operational elasticities
- (c) Reconciliation of the elasticity components with overall elasticity estimates
- (d) Appliance replacements

(e) Disaggregation of end-use energy consumption.

The ORNL Residential Model is installed and/or used for analysis by a large number of organizations. There also exist a number of versions and special applications of the model by DOE and ORNL, as well as ongoing model development at these institutions. It is therefore entirely possible that several of the changes or extensions suggested in the following discussion have already taken form elsewhere. An informal survey of the forthcoming versions and work in progress is presently underway by the authors of this report. For the discussion below, the analysis has focused on Versions 5 and 6 of the ORNL model. These are in current production use at EIA and changes in these are most likely to affect DOE conservation policy development and program planning and evaluation. Versions 7 and 8 are not sufficiently documented for critical comment.

1. Retrofit of Existing Residences for Better Thermal Performance

The ORNL Residential Energy Model capabilities in analyzing the impacts of retrofit programs and incentives to enhance thermal performance of existing housing were described in C.3. above. For this, the number of houses to be retrofit (or responding to retrofit incentives) each year and the corresponding impact on their energy use must be computed outside the model and provided as inputs. The cost of retrofitting such units can also be an input variable or be computed on the basis of the capital cost energy use technology curves for each existing housing type (curves similar to Figure I-2).

This procedure for modeling retrofits is appropriate where the retrofit is mandated and the number of homes to be reached and their expected changes in thermal performance are identified in the retrofit program (e.g., in federally undertaken weatherization for low-income households). It is very likely, however, that a large portion of the retrofit potential may be affected by less specifically targeted measures such as energy tax credits and low-interest loan programs which change investment costs for materials and installation. Perhaps as important, the by-now accustomed increases in fuel prices also provide incentives to retrofit as they increase operating costs. Both the capital cost and operating cost changes will alter the cost-efficient choice of structural thermal performance levels and fuels expenditures. Currently, these only affect new housing decisions. Furthermore, the present model structure represents only average thermal performance levels for each housing type (by region). Attempts to differentiate the response between those above and below the average levels, and thus having potential for specificially targeted retrofit programs, can only be undertaken outside the model.

The manner in which this might be remedied in the model appears to be complex. The number of homes retrofitted as the result of a retrofit program (e.g., tax credits, manufacturers' and installers' rebates, utility promotion and financing, homeowner information programs) would need to be calculated based on the initial costs and interest rates and implicit consumer discounting associated with each retrofit investment. For this to be possible, a division within the model would need to be made between existing houses of the same housing type but different thermal characteristics. Cost-efficient choices of fuel use vs. structural efficiency within such groupings would then be compared to the average, and a penetration algorithm might be postulated which depends on deviation from the average and the change in the fuel price levels. Differences in consumer behavior, both subjective and in response to market imperfections (e.g., levels of conservation information and awareness, incentives, etc.) might be represented for each grouping by different "implicit" discount rates to calculate separately weighted cost-effective choices. (See Section D.7 for more discussion of these behavior responses, such as response to information programs, and how they might be represented in the model.)

Alternatively, the market share of "retrofittable" housing could be estimated as a function of the cost of energy and the cost of retrofit. Both the accounting system and methodologies to undertake such a formulation need considerable research. Additionally, the information requirements to estimate the separate market shares of housing types by thermal performance as well as for various fuel and end-use characteristics are beyond nationally available statistics, though approximations may be possible.

Without significantly modifying the existing model structure, a partial solution to explicitly modeling retrofits may be found in identifying the market share of homes that are below a chosen level of thermal integrity. Data, for instance, from the National Interim Energy Consumption Survey (NIECS) on other insulation levels might be used to approximate the market share of housing that has potential for retrofit.* Reduction in this fraction and the gap between them and the average household's cost-effective choice of

*See Hittman Associates, Inc., "National Interim Energy Consumption Survey," Section D in Major Model and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, June 1980, for a review of the NIECS Survey.

fuel use vs. thermal performance could be estimated by a penetration function similar to that which is presently in the model; or this could be input exogenously. Similarly, changes in the implicit discount rate for that fraction of homes with retrofit potential could be hypothesized to represent increases in information and reduction in market imperfection from audits and other residential conservation service activities.

2. Retrofit of Existing Appliances for Better Efficiency

The ORNL model does not currently simulate retrofit appliance conservation programs. Changes in new appliance efficiencies, however, are simulated in a fashion similar to the choice of thermal integrity for new homes (see Section C.2). For this the technology submodel estimates energy use versus capital cost of equipment improvements. Given fuel and equipment prices and interest rates, the calculated cost-effective levels of operating costs versus new equipment costs then indicate the direction of new appliance purchases.

For existing equipment, however, the model does not retire the "inefficient" appliances in advance of their physical lifetimes. (See D.11.d for more discussion of the retirement function.) Again, as was the case with analysis of thermal integrity decisions, the ongoing fuel price changes and government program incentives which might influence existing appliance retirements are not represented in the model simulations.

A relatively simple modification of the model could be made to accept exogenously calculated appliance retrofit numbers, efficiency changes, and purchase prices for each appliance type. This would parallel the calculation permitted for retrofit of thermal integrity.

Modifications which would explicitly model the early retirement of appliances in order to purchase cost-effective features would entail the same difficulties as those discussed for changes in modeling thermal integrity. Furthermore, efficiency distinctions within an appliance type would require, in general, identification of the manufacturer and the model number. For heating and cooling and water heating equipment, this information may be available. Alternatively, where these exist, the possibility of switching from one type of heating or cooling appliance to another that provides the same final service (for instance, from resistance heating to heat pump or another compatible technology), market shares of each are already available in the model as are the energy use capital cost curves. The decision to retire the existing heating or cooling appliance in favor of a more efficient unit of the same fuel type could be modeled on the basis of some threshold difference between the minimized life-cycle costs for the end-use fuel category (or for the competing appliance technology) and the "actual" levels for the existing appliance.

3. Operational Conservation Measures

The effects of programs which restrict utilization of equipment, such as thermostat setbacks or lighting standards, are not explicitly found in the ORNL Residential Energy Model structure. The model does estimate the effects of operational responses to energy price changes through the utilization elasticities estimated for each end use or appliance (see Section C.6). These elasticities are in effect the short-term responses before changes in fuels, equipment efficiencies, or building thermal performance can be undertaken. These usage elasticities are estimated through engineering relationships which effectively adjust the basic income and price elasticities of fuel demands to reflect the differences in operational possibilities to reduce energy from the various appliances. Thus a 10 percent increase in electricity price might reduce space heating demand for energy by 4 percent (through lower house temperature) but refrigeration demand by only 0.5 percent. (See Section D.11.b. below for further discussion of these usage estimates.)

There is, however, presently in the model no way to depict the converse effect of usage changes or operational controls on energy use. A modification similar to the treatment of appliance efficiency standards could be employed. For this, a maximum energy use constraint reflecting the energy cutback from the operational standard could be programmed into the usage equation for the relevant appliance. The actual energy usage would then be the minimum of the standard or the usage resulting from the usage elasticity. For example, a 1°F cutback in the heating thermostat might reduce energy use by 5 percent. The usage resulting from the usage elasticities would be 95 percent or less, depending on whether price or income changes further reduced usage.

A drawback to this approach is that the lower energy use from the operational cutback would not itself affect any future elasticity. The usage elasticity would operate as if there were no cutback. Since the elasticity coefficients are based primarily on engineering estimates, it is difficult to go back to the data to reestimate these. Data from the Midwest Research Institute (MRI) appliance survey giving monthly usage per appliance for a national cross-section could perhaps assist in reestimating these. (See Section D.11.b for further discussion of these elasticities.)*

4. Rate Structure and Load Management

The ORNL model currently accepts forecasts of average prices of electricity, natural gas, fuel oil, and other (propane) as inputs, and computes residential demand on an annual basis. The same annual fuel price is applied to each end use. Because of this, the model cannot be used to evaluate the impacts of rate structure options, which include:

(a) Conventional declining block rates in which unit cost decreases with quantity consumed

(b) Level rates in which unit costs are constant

(c) Inverted or lifeline rates in which unit costs increase with quantity consumed

(d) Incentive rates in which usage in excess of a percentage of the prior year's usage (e.g., over 90 percent of prior year use) is priced above the base price.

Similarly, because the ORNL model only calculates annual energy use and does not calculate the hourly load profiles of electrical equipment usage, the model cannot evaluate load management programs. Load management programs include:

(a) Direct load control in which the utility can cycle customer equipment (e.g., air conditioners)

(b) Timers that limit the time of operation of appliances (e.g., water heaters)

(c) Storage devices that store energy at night (or over seasons) for use during peak periods of electricity use

(d) Time-of-use electricity rates.

*Midwest Research Institute. *Patterns of Energy Use by Electrical Appliances*, EPRI EA-682, Project 576. June 1979. Also Hittman Associates, Inc. "MRI Appliance Data Base," *Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis*. HC1011/002-80-931D2. June 1980.

It appears that it would be extremely difficult to modify the ORNL model to take full account of the effects of all the changes that might affect hourly rates and usage. More permanent national rate changes, however, might be approximated by appliance-specific reestimation with those rates and inputting appropriately "averaged" annual rates for these with estimates from outside the model. This still leaves open the possibility that even with the same average rate, new changes in the rate structure will again affect total demand. Reestimation of the average response, a provision for synthetic inputs from engineering energy load models aggregated across end uses appears to be the only solution, unless the model is entirely reestimated at the utility service area level for a shorter time period and engineering-determined load curves integrated into a new operational response submodule. In this, the change in load pattern would be treated as a change in the usage level.

Such a change in rates has in fact occurred since the model was first estimated, and the model structure should be adjusted for this. In 1970, the ORNL market share data base year, many electric utilities had special rates to promote electric space heating and most had declining block rates which effectively provided lower prices for space heating. In recent years many (perhaps most) utilities have instituted flat rate structures in which the unit cost is independent of quantity sold. Some utilities also have inverted rates in which the cost of electricity for space heating for a single-family home would be higher than the cost for other uses.

To adjust the existing model to reflect this changing space heating electric rate structure, several steps would be necessary. First, the model should be revised to accept a separate electricity price for space heating (or cooling, in some regions). Second, the market share elasticities should be reexamined for consistency with the electric space heating (or cooling) rate. Third, rate developments since 1970 and potential future developments should be examined to develop an input price of electricity for space heating (or cooling).

5. Alternative Energy Supplies - District Heating

The ORNL Residential Energy Model calculates consumption of electricity, natural gas, fuel oil, and other (primarily propane). It does not currently simulate use of steam for district heating. Similarly, it cannot evaluate the market penetration of windmills, photovoltaics, and total energy systems in the residential sector.

District heating systems provide steam, generally for space heating apartment buildings. This is available in 43 cities in the United States. District heating is apparently included within the other fuel use in the current model, but the other fuel price is the price of propane, which is quite expensive relative to district heat where it is available.

Several steps would be required to explicitly treat district space heating within the ORNL Residential Energy Model. First, the market share equation for space heating would need to be modified to reflect district heating. The district heating market share applies to space heating in limited geographical areas within the model's coverage; the market share would need to be multiplied by the fraction of houses where district heat is available. Market share elasticities, including district heating, would need to be developed. Second, the model would need to be modified to accept an input price of district heat. Third, technology characterization function would need to be added for district heating. Fourth, the section of the model which prints out forecasts would be modified to display projected district heating.

6. Alternative Energy Supplies - Solar Space and Water Heating

The current version of the ORNL Residential Energy Model accepts as input a function that relates installed space heating and water heating capital cost to annual energy use (efficiency). Figure I-2 presents an example of this technology characterization function. As described earlier, life-cycle cost minimization using this efficiency-versus-capital cost trade-off indicates the direction for new consumer purchases of housing energy conservation installations and of appliance investments. (See Section B.3). Energy use per house per annum may be reduced by installation of more efficient systems, with an associated increase in installed costs.

With appropriate data, the technology characterization functions could be modified to reflect solar space and water heating options, leading to further reductions in energy use at greater installed costs. However, the resulting model output would only indicate the utilization of the backup fuel and would not reveal the solar contribution.

Solar space and water heating could be explicitly treated by modifying the ORNL model. The structure of this modification is displayed in Figure I-4. The first step, embodied in the existing model, is the choice of a fuel for space heating and for water heating. The second step would be the choice between conventional fuel-using systems or solar with, for instance, electric backup. The third step would be selection of the efficiency for the conventional system and the efficiency as well as solar contribution for the solar

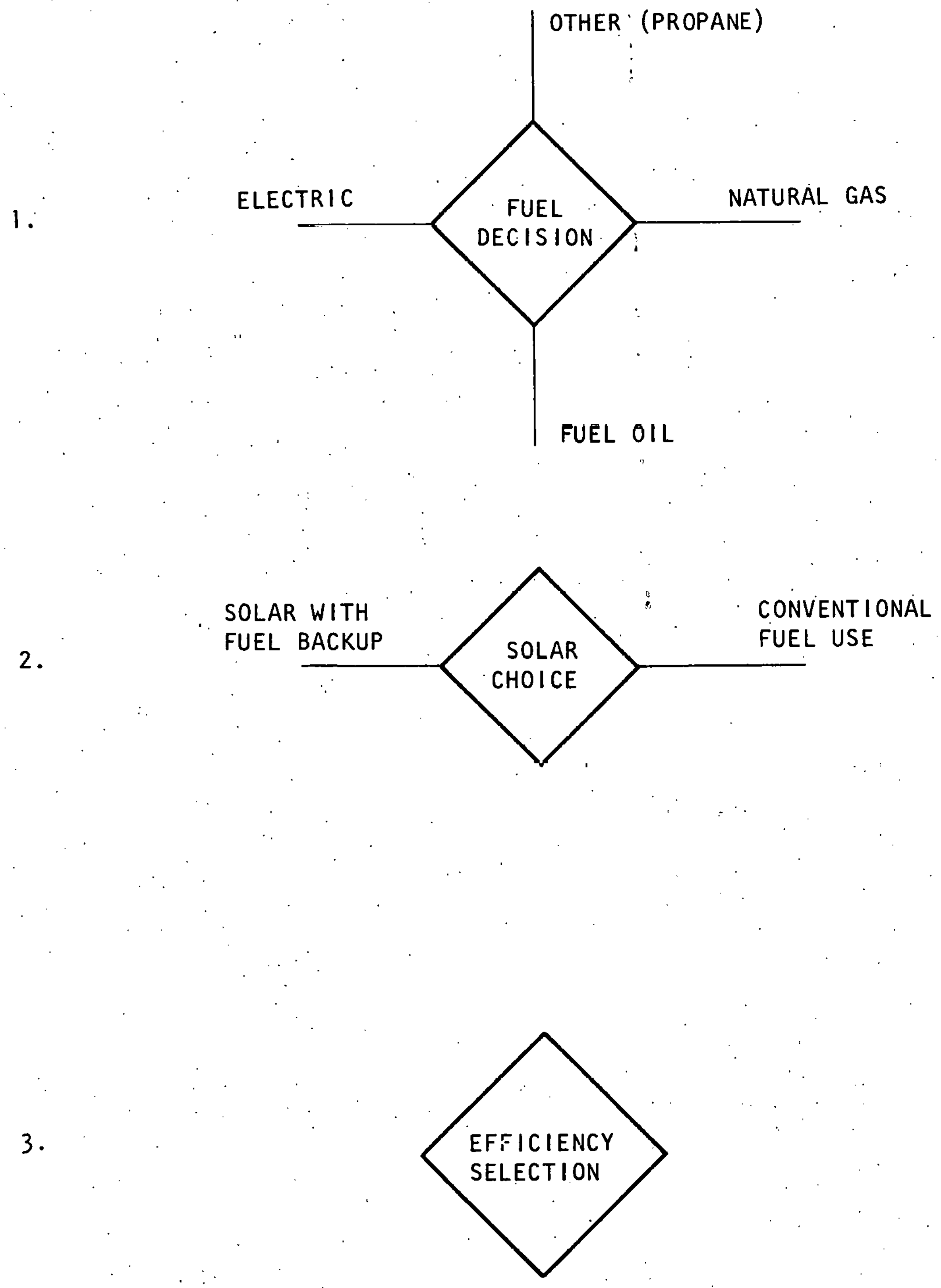


Figure I-4. Structure of ORNL Residential Energy Model Modifications to Explicitly Treat Solar Space and Water Heating system, by fuel type. This structural modification involves adding the second step, the solar/conventional choice, to the model and providing a technology characterization function (e.g., Figure I-2) for solar with fuel backup.

These modifications would have several benefits:

(a) Embodying solar options within the same model used for conservation policy analysis and mid-range forecasting

(b) Providing a capability of simulating policies to increase the market penetration of solar

(c) Providing the capability to simulate the impacts of policies which favor both conservation and solar energy.

Data in the technology curves life-cycle cost analysis and consumer demand appear to be available from solar space and hot water modeling analyses sponsored by DOE and integrated into market development and commercialization models. Such models include the Arthur D. Little's Solar Market Development Model, the Orkand Corporation's Simulation of Solar System Performance and Market Penetration Model (SOLARSIM), and Mitre Corporation's System for Projecting the Utilization of Renewable Resources (SPURR).* A major effort, however, would be necessary to make the data fully compatible with ORNL residential sector definitions and the parameter estimates from differing sources.

7. Consumer Behavior Toward the Choice of More Efficient Equipment - Discount Rates and Market Penetration

The ORNL Residential Energy Model analysis of consumer decisions with respect to more efficient equipment was discussed in Section B.3 under efficiency elasticities and market penetrations. For such decisions, the model represents the consumer as choosing the technologies available for a given end use and fuel price in terms of life-cycle cost comparisons of various equipment available and combinations of equipment cost and operating cost. The model assumes and estimates for each appliance service, a "real" interest rate with which the future operating expenses (and savings) can be evaluated. Ideally, the consumer would choose from all combinations the "cost-effective" or minimum life-cycle cost option, but the observed actual choices differ from this. The model assumes

Sources given in the Bibliography. See also Hittman Associates, Inc. Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, Section K.

that market imperfections and other more subjective reasons (lack of information, imperfect financial markets, uncertainties, etc.) are the reason for this difference. The term "implicit discount rate" can be used to combine the various imperfections that distort the decision away from the cost-effective one. A variety of studies suggest this distortion, if applied as an actual discount rate in the life-cycle cost analysis, is equivalent to a rate of 30 percent to 200 percent, depending on the appliance involved.*

For market penetration or calculation of the actual efficiency levels purchased, the model further assumes that as fuel prices rise, the cost of these imperfections to the consumer rise and thus they will be reduced; the discount rate and the gap between actual and optimal purchases decline with rising fuel prices.

The ORNL modelers admit that this approach, though based on reasonable theoretical assumptions and providing "reasonable" empirical results, is for the most part "ad hoc" (Hirst and Carney, 1978, p. 71). This lack of a firm theoretical and empirical foundation limits the model's contribution to analyzing changes in consumer behavior. Several areas where this weakness affects model analysis are:

(a) Conservation information programs that could affect the imperfect information consumers receive on conservation opportunities, the procedures to carry out the conservation investments, and the net savings from such operations

(b) Opportunities to obtain appropriate financing (e.g., utility financing); this may affect both the capital cost and the consumer's "view" or discounting of the equipment benefits

(c) Conservation activities, including (a) and (b) above which have differential effect across income groups or other classes of consumers, where the implicit discount rates of these groups may differ and be differentially changed.

A variety of DOE-sponsored studies are presently in progress at ORNL and elsewhere to better understand consumer decision making. To some extent, constructive findings may be incorporated into the model by varying "real" interest

See, for example, O'Neal, D. et al., "An Estimate of Consumer Discount Rate Implicit in Single-Family Housing Construction Practices," ORNL working paper. June 1980.

rates according to the proposed conservation program or by adjusting the penetration function to reflect changes in market distortions. More complete analysis would probably involve disaggregated modeling of consumers' behavior beyond the scope of the ORNL model. The results of such modeling, however, probably could be summarized and interpreted into proxy interest rates suitable for ORNL model simulation of aggregate impacts.

8. Renter/Landlord/Apartment Building Analysis

The ORNL Residential Energy Model simulates energy use by building type: single-family, multifamily, and mobile home. The existing model can approximate the impact of some types of conservation policies by building type, for instance, tax credits, which affect the initial cost/annual energy use trade-off, and retrofit thermal integrity programs, based on an input number of homes retrofit, by building type. Although for this analysis initial cost/annual energy use trade-off functions are input to the model for each building type, the "real" interest rate used to determine the minimum life-cycle cost choice of new building thermal integrity and of new appliance efficiency is the same for all building types.

Modifying the ORNL Residential Energy Model to accept interest rates by building type would permit approximate modeling of conservation behavior by owner type. In 1977, the relationship given below prevailed between building and owner types.*

Building Type	Owner-Occupied	Renter-Occupied
Single-family	79%	21%
Multifamily	12%	88%
Mobile Home	82%	18%

Separate interest rates input by building types would help to reflect apparent differences in conservation market penetration between single-family and multifamily units as shown below:**

**U.S. Department of Commerce, "Annual Housing Survey: 1977," 1979, p.1.*
***Energy Information Administration, "Residential Energy Consumption Survey: Conservation," February 1980, p. 17.*

Conservation Activity	Single-family Detached	2-4 Units
Storm windows	63%	57%
Storm doors	67%	41%
Attic insulation	77%	35% *
Wall insulation	54%	28% *

Conservation behavior not only depends on building and appliance ownership but also on the utility billing; one study** indicated that master-metered apartments use an average of 35 percent more electricity than separately metered apartments. Differences in metering can be reflected in regional application of the ORNL model, once separate interest rate inputs are accepted by building type: the extent of master-metering ranges from 18 to 77 percent between cities.** Analysis on metered versus non-metered apartments from the National Interim Energy Conservation Survey may help to better define these effects and their determinants.

Once separate interest rates are accepted by building type, the ORNL Residential Model could be used to simulate conservation programs which affect the implicit interest rate market imperfection and distortions and subjective factors used in consumer conservation decisions. Low-interest loans and residential conservation programs targeted to apartment dwellers or landlords are examples of such programs.

9. Utility Activities

Actions taken voluntarily or mandated for private and public utilities to foster increased residential energy conservation are only partially amenable to analysis with the present ORNL model structure. Several applications and extensions of the model to include these simulations are given below. This discussion incorporates several of the changes and analytical discussions from other sections of this chapter.

Examples of potential residential energy conservation activities involving utilities include:

**Approximately 40 percent did not know whether building had insulation.*

***Midwest Research Institute, "The Energy Conservation Implication of Master Metering of Electric Service in Apartments," Proceedings of Second Annual Conference on Energy, Rolla, MO, 1975.*

(a) The Residential Conservation Service (energy audits)

(b) Public information programs

(c) Changing from declining block to level or inverted rate structures, seasonal rates

(d) Marginal cost rates for new customers

(e) Penalty rates for increased usage (or for failure to decrease usage)

(f) Low- or no-interest loans for retrofit conservation activities

(g) Free conservation equipment (e.g., showerhead flow restrictors)

(h) Buying old, inefficient appliances (e.g., frost-free refrigerators)

(i) Energy conservation standards for new customers (e.g., new electric heating customers must have a specified level of insulation)

(j) Alternative energy programs (solar-electric incentive rates, loan programs)

(k) District heating

(l) Prohibitions on new electricity uses

(m) Load management

(n) Time-of-use rates

(o) Customer energy storage incentives

(p) Voltage reduction.

The Residential Conservation Service and public information programs can be approximately simulated with the existing ORNL Residential Energy Model. The interest rates used to determine minimum life-cycle cost equipment choices can be reduced to reflect better information. The number of retrofit units can be increased, reflecting improved knowledge of retrofit opportunities. However, these programs could be modeled more explicitly by adapting the ORNL model to accept an input percentage or Btu per household reduction in energy use due to improved information.

The ORNL Residential Energy Model currently accepts a single average price for each type of fuel. Electric and some gas utilities, however, are effectively increasing the price charged for space heating and for space cooling by changing from declining block rate structures to level, inverted, and seasonal rate structures. In addition, most utilities have abolished promotional rates for electric space heating and all-electric homes. Modeling the impact of these changes in rate structure would require adapting the ORNL model to accept separate prices for space heating and space cooling. In addition, the fuel price-equipment ownership elasticities should be adjusted to reflect actual rates, rather than average prices, in the historical period. Data for this adjustment can be obtained from the Federal Energy Regulatory Commission publication "All-Electric Homes."

As in the analysis of most utility programs, modeling the impact of rate structure changes presents aggregation problems in applying the ORNL Residential Model to regional or national data. Individual utility rates could be weighted according to:

(a) Number of residential customers

(b) Residential sales

(c) Estimated sales by end use.

Alternatively, the model can be applied to an individual utility service area to estimate rate structure impacts for the area.

Marginal cost rates for new customers and penalty rates for increased (or failure to decrease) usage cannot be modeled in the current ORNL code. The model could be modified to accept separate fuel price forecasts for existing and new homes; additional data and modifications would be necessary to include new owners of old homes on the higher rates. Penalty rates would be difficult to model; these rates apply only to homes with a year's sales history. The ORNL model might be modified to provide an iterative solution for the energy price and quantity consumed in existing homes, embodying the rate structure within the computer code. An initial estimate of average energy price to existing homes would lead to a consumption estimate per home. This estimate of consumption per home would be compared to the prior year's consumption, providing a revised estimate of energy price. The process would continue until the price estimates converged.

Utility retrofit programs could be modeled using the existing ORNL code by modifying the input number of homes weatherized and the cost of weatherization. However, explicit modeling of retrofit programs would require model modifications so that the number of homes and appliances retrofitted as a result of incentive programs would be computed based on the initial cost and interest rate associated with retrofit investments. An intermediate step in modeling appliance retrofit programs would be to extend the model's current exogenous weatherization logic to appliances, inputting the number to be replaced or adapted for improved efficiency (e.g., water heater wrap).

Utility energy conservation standards for new customers could be incorporated in the ORNL Residential Model's existing logic, which accepts building and appliance efficiency standards. However, in regional or national application, rather than making service area impact estimates, the utility program should be weighted by the utility's share of regional residential energy sales. Thermal integrity standards for new owners of existing homes could be incorporated in the model's retrofit inputs.

Alternative energy programs, such as incentives for solar or wood heat with electric backup, and district (steam) heating are not explicitly treated in the current ORNL Residential Model. Similarly, prohibitions on use of electricity for resistance space heating or water heating in new dwellings cannot be modeled with the current code. These programs could be modeled by:

(a) Adding a distinct "alternative energy" fuel type ("other" fuel in the current model is primarily propane) with an input market share for new homes, allocating remaining homes to other fuels

(b) Permitting the user to prohibit a fuel choice for an end use in new homes, allocating fuel choices to remaining fuel types.

More explicit modeling approaches for alternate energy programs could include:

(c) Adapting the initial cost-annual energy use tradeoff curves for the backup fuel (e.g., electricity for solar space heat with electric resistance backup) to reflect alternative energy options and incentives

(d) Adding alternative energy price, market share, and equipment costs data, reflecting incentive programs, and modeling alternative energy market penetration analogously to penetration of fuels

(e) Revising the initial cost of new electric space and water heating equipment to remove the resistance option.

The ORNL Residential Energy Model projects residential electricity use on an annual basis only. Utilities, however, are engaging in several types of programs to increase residential load factor and reduce peak-hour use involving daily and hourly demands. Similarly, load management programs involve utility control of peak-hour use, such as radio-actuated cycling off air conditioners for 15 minutes per hour and interlocking appliances to prohibit simultaneous operation. Utility customer storage programs include demonstrations of heat and cool storage and incentive rates for storage water heaters. Time-of-use electric rates provide incentives to reduce peak-hour usage.

Changes in the ORNL Residential Energy Model to incorporate the peak-load and hourly demand analysis would require extensive and very awkward revisions in the existing structure. It would be more efficient to adapt the ORNL model to a utility service area and then link the model's annual energy consumption projections, by end-use, to a residential peak-demand model which would make adjustments to the basic annual demand. Efforts in this direction are currently in development at Lawrence Berkeley Laboratory (LBL).

10. Regional Energy Use and Conservation Activities

The ORNL Residential Model has been disaggregated to make regional projections at several levels of regional detail. The model has been applied for nine Census regions (Kurish and Hirst, 1977); for 10 DOE regions (Hirst et al., 1977), for states (Sakolosky and Muttardy, 1979); and for service areas of 10 electric utilities (work in progress at Lawrence Berkeley Laboratories).

The studies listed above relied primarily on the national model structure and coefficients, but used regional input data for:

(a) Number of homes by building type

(b) Market shares for housing and equipment

(c) Fuel prices and income

(d) Number of low-income units to be retrofitted.

Several major improvements would be useful to better differentiate regional responses and impacts. These are discussed below.

a. Technology Coefficients. Estimates of these energy use (efficiency) versus capital cost curves for individual structures and for appliances should differ depending on the climatic conditions of the region (e.g., energy use and efficient use of equipment for regions with a mean winter temperature of 45°F differ from those with 25°F). The various regional models do not seem to reflect these differences.

Data for estimating the separate regional capital cost versus thermal performance curves for housing appear to be available from the ongoing buildings energy use estimates from models such as the DOE-2 model housing runs for the Buildings Energy Performance Standards (BEPS) analysis. Similarly, regional data for the capital cost versus appliance efficiency curves should be available from the appliance efficiency standards analysis at DOE. (See, for example, Technical Support Document No. 5 for Energy Efficiency Standards for Consumer Products, DOE/CS/BCS, May 1980.)

b. Elasticity Estimates. The reports on the regional models indicate that the market share usage and technical efficiency elasticities employed in the various regional models depend to a considerable extent on those estimated for the national model. To the extent that individual behavior patterns vary regionally, these could distort the regional results.

Recent versions of the regional models apparently could now adjust the national elasticity estimates to the approximate regional responses via regionally estimated overall fuel usage elasticities.* Since the overall fuel usage elasticity should equal the sum of the other three elasticities for that fuel, it is possible to use this as a control total to adjust the others (see Section D.11.c for further discussion). A variety of problems, however, exist in making such adjustments. In particular, the technological efficiency elasticities depend on the technology model coefficients, which do not vary by region (see a. above). Additionally, this adjustment procedure does actually reflect regional differences in behavior that differentiate specific changes in usage, market shares, and technical efficiencies.

When estimates are available for regional estimation of the technology coefficients, perhaps from DOE appliance efficiency standards analysis (see Technical Support Document No. 5 of Energy Efficiency Standards for Consumer Products), then a partial solution will exist. Appropriate regional technical elasticities then require adjustment of only the usage and market share coefficients.

**For such estimates, see Sakolosky and Muttardy, February, 1979.*

c. State-Level Analysis. The 10 DOE region version of the ORNL model is an ongoing, regularly updated entity used for analysis at EIA (as the Structural Residential Energy Use Model) and as part of the DOE Midterm Energy Forecasting System (MEFS); this regional version is running at a number of other institutions as well as at ORNL. Similar application of the state-level model has not occurred. It is, in fact, in disuse.

The State Residential Energy Demand Model was developed in 1978-1979 by Tetra Tech for DOE.* For this, the ORNL national model was reestimated and initialized for state- or sometimes regional-level information. Considerable attention was given to reestimating a state-level housing submodel and attempting to correct deficiencies in the regional elasticities of demand. The model has been run and updated to be consistent with the ORNL Model National Version 5. However, at this point no use is being made of the model since state-level data forecasts and inputs have not been high priority at DOE.

The state-level analysis of residential energy demand can be of considerable importance to energy conservation policy and planning. The Tetra Tech analysis underlines this in the following example (Sakolosky and Muttardy, April 1979, pp. 39, 40).

> The differences between energy consumption patterns in individual states are of critical importance to government and utility planners. California's total fuel consumption level exceeds Arizona's by a factor of 7 in 1990 so that even small percentage savings in energy use in California could lead to substantial actual savings. However, Arizona's households are projected to consume 15 percent more fuel per household than California's in 1990, reflecting a large increase in energy use intensity over the simulation period, particularly in electricity. Arizona is thus an important area for implementing electricity conservation programs. Its overwhelming dependence on electricity indicates the importance of seeking alternative energy sources to supply its fuel requirements.
>
> Differences between California and Arizona's energy requirements exemplify intraregional differences which exist among states within Federal regions. These differences impact strongly on

**Sakolosky and Muttardy, February 1979 and April 1979.*

individual state's responses to market forces and mandated federal energy programs. For energy planning and analysis, it is important to simulate energy demand at the state level to judge the effectiveness and fairness of proposed programs on the diverse states and to identify sensitive areas of program impact.

To better apply the state-level model, more interest in state-level forecasts would need to be forthcoming from DOE, and efforts would have to be made at EIA to collect and project state-level input data for the simulations. Reestimation of the elasticities and the technology coefficients could follow after the initial interest in its applications.

11. Technical Improvements in the Structure of the Base Case of the ORNL Residential Energy Model

The specification of the model's base case could be improved by refinement of the input data and the model's algorithm. Suggestions for several of these are presented in the following discussion.

a. Market Share Elasticity Coefficients. The ORNL Residential Energy Model accepts long-run equipment market share elasticities. These elasticities relate the share of new houses choosing each fuel for each end use to fuel prices and income. The elasticities were estimated using 1970 Census of Housing data.

The elasticities should be updated because the original data used to derive these coefficients are 10 years old and not as relevant to present-day applications of the model's algorithms. Energy prices have risen dramatically since 1970, so the current elasticities are being applied to energy prices that can be considerably outside the historical range of data. Reestimating the elasticities using recent data should improve the accuracy of the model's market share predictions. Also, the Census data set used in the current estimates provides measures for the 1970 stock of houses using fuels for each end use; in contrast, the elasticities are applied not to the stock but to new construction. Thus it would be desirable to reestimate the elasticities using new construction market share data.

The data set which could be used to determine new estimates for the space heating market share elasticities is the U.S. Bureau of Census Construction Reports: Characteristics of New Housing, Series C-25. This source has the fuel used in new single-family and in new multifamily homes, by year built, and by four regions of the United States. Comparable energy price and income data can be developed from Department of Energy and Bureau of Census publications. The National Interim Energy Consumption Survey (NIECS) results are also amenable to this analysis, although the data are not for new housing alone.*

Once the new elasticities are estimated, these values may be input to the ORNL Residential Energy Model and the results compared to forecasts using the old elasticities.

b. Operational Elasticities. The ORNL model employs short-term usage elasticities of fuels demand per equipment to represent consumer behavior during the short-run period when there is no opportunity to make new equipment investments or to change fuels. These operational changes would include thermostat setbacks for heating or increases for air conditioning, cutbacks in lighting, reduced use and/or temperature of hot water, etc. Estimates of these fuel price and income elasticities for each end use rest on engineering judgments of ORNL scientists. Empirical verification has apparently been made by comparison to the overall short-run fuel demand estimates in other studies (Hirst and Carney, 1978, p. 33).

The model would benefit from independent estimates and verification of these. A potential source might be the Midwest Research Institute's individual electric appliance metering data by household for 1976. This relatively small cross-sectional sample for 12 monthly readings would probably not provide much variation in prices for any individual household, but the differences in income response could be statistically significant.**

c. Reconciliation of the Elasticity Components With Overall Elasticity Estimates. The model estimates the demand for each fuel with respect to changes in its own and other fuel prices, income, and climatic variables. The demand elasticity for this fuel is disaggregated into three components of household behavior: market share equipment ownership elasticities, which reflect changing fuel consumption due to switching from one fuel-using equipment to another when fuel price changes; usage elasticities which measure change in intensity of equipment use with respect to changing fuel prices; and technical efficiency elasticities which

---

*See Hittman Associates, Inc., "National Interim Energy Consumption Survey," Section D in Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, June 1980, for a review of the NIECS Survey.

**Midwest Research Institute. Patterns of Energy Use by Electrical Appliances, EPRI EA-682, Project 576. June 1979.

reflect switching from one fuel-using equipment to another which uses that fuel more efficiently. Each of these elasticities is estimated independently in the model simulation. The question is whether in the simulation these separate elasticities sum to the appropriate overall fuel elasticity, since they are responses reflecting somewhat different behavioral reasoning. The original model (Hirst and Carney, 1978, p. 32) provided a correction for this by estimating an overall fuel demand elasticity, and using the simulation of this as a control total to which the other three would be adjusted by the user. If this adjustment is not made (which appears to be the present practice), then it is possible that the sum of the three components, which were not simultaneously estimated, could drift away from the total fuel demand response indicated from the overall estimate.

Explicit corrections or checks for this possible variation could be important for overall fuel use estimates as well as analysis of regional variation. Solutions might include simply pointing out for the user the comparisons of the overall versus the sum of components, or alternatively developing a correction internal to the model.

If either of these steps were to be taken, then it would be important to also update the "overall" demand elasticities estimate. The original estimates were from state-level data from 1951 to 1974. Recent fuel use and price history data are available from the Department of Energy EIA and from trade associations (American Gas Association, Edison Electric Institute). Energy prices have increased significantly since the coefficients were first estimated; reestimation could significantly improve model accuracy in forecasting residential energy usage under conditions of high energy prices.

d. Appliance Replacements. Current analysis of appliance choice focuses on purchases of appliances for new households and replacement appliances for those that have been retired. The difficulties of this formulation in analyzing retrofit behavior were discussed in Section D.2. In the present model formulation, where appliances are replaced only upon wearing out or losing their usefulness, the estimates of the removal rates become even more important in evaluating long-term savings from appliance efficiency standards.

The current ORNL model, Version 6 computer listing, employs a percentage decay function consistent with estimated equipment lifetimes. This is likely both to overstate removals during the early portion of appliance life and to retain some too long. An improvement might be to use Arthur D. Little appliance data from the DOE appliance efficiency studies (Energy Efficiency Standards for Consumer Products, Technical Support Document No. 5, U.S. DOE/CS/BCS) and estimate a logistic curve that has few early retirements, the bulk near the mid to late term and a few that last much longer.

e. Disaggregation of End-Use Energy Consumption. The ORNL Residential Energy Model can be modified to reflect more accurate disaggregated information or end-use energy consumption. The current model does not present significant differences in consumer behavior for each end use across housing and user markets. In a recent paper "Appliance Acquisition Mechanisms and Energy Consumption Throughout U.S. Housing: A Disaggregated Probe," Dr. Fred Reid indicated that appliance acquisition decision making differs among building types and between new and replacement markets.

The ORNL model could probably be modified with relative ease to accept specific data for these added markets; the main effort would be to develop consistent data for each market.

E. Bibliography

American Gas Association. (Year) Gas Facts. 1950-1979.

American Petroleum Institute. Petroleum Facts and Figures, 1979 edition. Washington, DC, 1980.

Cohn, S., E. Hirst, and J. Jackson. Econometric Analysis of Household Fuel Demand, ORNL/CON 7. Oak Ridge National Laboratory, March 1977.

Delene, J. A Regional Comparison of Energy Resource Use and Cost to Consumer of Alternate Residential Heating Systems, ORNL/TM-4688. Oak Ridge National Laboratory, November 1974.

Edison Electric Institute. Statistical Yearbook of the Electric Utility Industry for 1978, No. 75-39, November 1979; previous issues from 1950 to 1973.

Hirst, E., and J. Carney. The ORNL Engineering-Economic Model of Residential Energy Use, ORNL/CON-24. Oak Ridge National Laboratory, July 1978.

Hirst, E., and J. Kurish. Residental Energy Use to the Year 2000: A Regional Analysis, ORNL/CON-17. Oak Ridge National Laboratory, November 1977.

Hirst, E., and J. Carney. Residential Energy Use to the Year 2000: Conservation and Economics, ORNL/CON-13. Oak Ridge National Laboratory, September 1977.

Hirst, E., et al. An Improved Engineering-Economic Model of Residential Energy Use, ORNL/CON-8. Oak Ridge National Laboratory, April 1977.

Hirst, E., et al. An Improved Engineering/Economic Model of Residential Energy Use, ORNL/CON-8. Oak Ridge National Laboratory, February 1977.

Hittman Associates, Inc. Development of Residential Buildings Energy Conservation Research, Development and Demonstration Strategies, HIT-681. August 1977.

Hittman Associates, Inc. Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, HC1011/002-80-931D2. June 1980; particularly Residential Sections: A. Oak Ridge National Laboratory Residential Energy Model, E. National Interim Energy Consumption Survey, and I. Patterns of Energy Use by Electrical Appliances Data Base.

Hoskins, R., and E. Hirst. Energy and Cost Analysis of Residential Refrigerators, ORNL/CON-6. Oak Ridge National Laboratory, January 1977.

Hoskins, R., and E. Hirst. Energy and Cost Analysis of Residential Water Heaters, ORNL/CON-10. Oak Ridge National Laboratory, June 1977.

Hutchins, P., and E. Hirst. Engineering-Economic Analysis of Single Family Dwelling Thermal Performance, ORNL/CON-35. Oak Ridge National Laboratory, November 1978.

Hutchins, P., and E. Hirst. Engineering-Economic Analysis of Mobile Home Thermal Performance, ORNL/CON-28. Oak Ridge National Laboratory, October 1978.

Jackson, J. "Conservation Policy Modeling Capabilities of the ORNL Residential and Commercial Models," (Draft). Oak Ridge National Laboratory, February 1980.

Kurish, J., and E. Hirst. Residential Energy Use Models for the Nine U.S. Census Divisions, ORNL/CON-11. Oak Ridge National Laboratory, April 1977.

Lin, W., E. Hirst, and S. Cohn. Fuel Choices in the Household Sector, ORNL/CON-3. Oak Ridge National Laboratory, October 1976.

McCormick, Thomas. "Users Guide to the Oak Ridge National Laboratory Residential Energy Demand Model," MIT-EL 79-042WP. Massachusetts Institute of Technology, August 1979.

McGrady, P., and G. Oleson. "Review of Residential Sector Energy Consumption Information Requirements, EIA," (Draft). 1980.

Midwest Research Institute. "The Energy Conservation Implications of Master Metering of Electric Service in Apartments." In: Proceedings of Second Annual Conference on Energy, Rolla, Missouri, 1975.

Midwest Research Institute. Patterns of Energy Use by Electric Appliances, EPRI EA-682. January 1979.

O'Neal, D., K. Corum, and J. Jones. "An Estimate of Consumer Discount Rate Implicit in Single-Family Housing Construction Practices," Working Paper. Oak Ridge National Laboratory, June 1980.

O'Neal, D. Energy and Cost Analysis of Residential Space Heating Systems, ORNL/CON-25. Oak Ridge National Laboratory, July 1973.

Papadopoulos, A., and S. Berger. Energy and Cost Analysis of Room Air Conditioners, ORNL/MIT-268. Oak Ridge National Laboratory, February 1978.

Reid, F. "Appliance Acquisition Mechanisms and Energy Consumption Throughout U.S. Housing: A Disaggregated Probe," (Draft). Berkeley, California, January 1980.

Sakolosky, D., and A. Muttardy. Final Report, State Level Residential Demand (SRED) Model Version IV. Tetra Tech, Inc., Arlington, Virginia, February 1979; also Version V, April 1979.

U.S. Department of Agriculture, Statistical Reporting Service. Agricultural Prices, Annual Summary 1975. June 1976; also earlier annual issues.

U.S. Department of Commerce, Bureau of the Census. Construction Reports: Characteristics of New Housing, Series C-25, 1978.

U.S. Department of Commerce, Bureau of the Census. Annual Housing Survey: 1977 Current Housing Reports, United States and Regions, H150-77-(AE). U.S. Government Printing Office, 1979.

U.S. Department of Commerce, Bureau of the Census. 1970 Census of Housing, Detailed Housing Characteristics, United States Summary, HC(1)-B1. 1972; also 1960 Census of Housing.

U.S. Department of Commerce, Bureau of the Census. "Population Estimates and Projections - Estimates of the Population of the United States by Age, Sex, and Race: July 1, 1974 to July 1, 1976," Current Population Reports, Series P-25, No. 643, January 1977; also earlier issues.

U.S. Department of Commerce, Bureau of the Census. "Population Characteristics - Household and Family Characteristics: March 1976," Current Population Reports, Series P-20, No. 311, March 1976; also earlier issues.

U.S. Department of Energy. "Technical Support Document No. 5, Energy Efficiency Standards for Consumer Products." DOE/CS/BCS. May 1980.

U.S. Department of Energy, Energy Information Administration. "Residential Energy Consumption Survey: Characteristics of the Housing Stock and Households, 1978," DOE/EIA-6207/2. February 1980.

U.S. Department of Energy, Energy Information Administration. "Residential Energy Consumption Survey: Conservation," DOE/EIA-0207/3. February 1980.

U.S. Department of Energy, Federal Energy Regulatory Commission. "All-Electric Homes in the United States Cities of 50,000 and More." U.S. Government Printing Office, January 1978.

U.S. Department of the Interior, Bureau of Mines. "Sales of Fuel Oil and Kerosene in 1974." 1975; and earlier reports.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

II. MODEL FOR MICRO ANALYSIS OF HOUSEHOLD ENERGY CONSUMPTION

[Micro Analysis of Transfer to Households/Comprehensive Human Resources Data System (MATH/CHRDS)]

A. Introduction

The MATH/CHRDS model provides simulated data files for analyzing the distributional effects of the Department of Energy's household energy conservation programs across various socioeconomic subgroups. This chapter discusses critical elements of the model structure and attempts to identify its present applications and its potential to address future issues and programs of importance to residential energy conservation policy analysis.

A brief background to the model, its use, and a summary of the findings pertaining to the model are presented below. The major sections of this chapter then expand on these. Section B provides an overview of the present model structure. Section C offers an assessment of the MATH/CHRDS applications, examining its strengths and limitations and suggesting areas where it may be modified to better assist analysis of residential energy conservation.

1. Background

MATH/CHRDS provides a synthetic micro household data base created by augmenting and updating base-year survey information. The micro simulation model then extends this to project results of a household energy consumption survey that might have taken place in a future year by updating demographic, economic, and energy-related characteristics. Household expenditures change as a function of energy prices, incomes, housing and energy-using appliance stocks, fuel choices, and energy efficiencies of appliances and structures. Socioeconomic variables related to the households include income levels, age, regional location, housing type, employment, and family size. With these, the model provides a basis for evaluating the impacts on household energy expenditures due to trends and policy changes in energy prices, appliance efficiency levels, energy use patterns, and demographic and socioeconomic variables. The model also provides detail on household energy use for transportation, but the present discussion focuses on energy use within the buildings.

MATH/CHRDS employs microanalytic simulation techniques developed originally for planning and evaluation of public welfare (transfer) policies in the 1960s. The Micro Analysis of Transfers to Households (MATH) model by Mathematica Policy Research, Inc., is basically a modification of the Transfer Income Model (TRIM) that was developed for analysis of tax and transfer payment systems of Income Maintenance Programs. This structure has been extended to include detailed characteristics on residential energy use and expenditure in the Comprehensive Human Resources Data System (CHRDS). In combining these two, the capability and data are developed for analyzing the impacts of energy conservation policy disaggregated in detail to the household level. Using these, the MATH/CHRDS model can simulate the distributed impacts of proposed household energy conservation policy and present this in the form of a synthetic sample survey showing the effects on each household of the energy changes. The major impact variables are the distribution of household energy expenditures as these are affected by changes in energy prices in combination with changes in appliance efficiency levels, energy use patterns, and household demographic and socioeconomic characteristics.

The MATH/CHRDS model currently interfaces with EIA's Midterm Energy Forecasting System (MEFS) to provide the detailed distributional impacts analysis of the Annual Report to Congress. Major requests for model outputs at DOE primarily take the form of more detail from existing runs that are further disaggregated by distribution of income, location, or building structure. Recent work has involved use of the model's update to 1975 to develop the household sector of the End Use Consumption Data Base, Household Sector, 1975.*

The model development is the outgrowth of work by Mathematica Policy Research, Inc., for the Federal Energy Administration and later for EIA. The work is ongoing, but the basic theoretical model design and implementation are addressed in "Distributional Impact of Energy Policies: Development and Application of the Phase I Comprehensive Human Resources Data System" and in "MATH/CHRDS: Technical Description" by Jill King and Mathematica Policy Research. The documents, "MATH: User's Guide" and "ENERGY: User's Guide," deal with the running of the system. MATH/CHRDS application in policy analysis is illustrated in the analysis memorandum from EIA, "A Distributional Analysis of the 1985 Energy Projection for the Annual Report to Congress of the Energy Information Administration."*

**Additional summary information on the model structure, policy variables, model inputs, outputs, data sources, and accessibility are introduced in the publication, Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, Section D, "MATH/CHRDS," and Section F, "Energy Consumption Data Base." Hittman Associates, Inc., June 1980.*

These documents, together with discussions with the model developers and users at EIA, form the basis for the analysis that follows.

2. Summary

MATH/CHRDS can provide household-level simulations of the distributional impacts of proposed residential energy conservation programs and policies. Changes in household energy expenditures and fuels use can be analyzed across geographical, socioeconomic, and housing characteristics as these are affected by changes in energy prices, appliance efficiency levels, energy use patterns, and different assumptions about targeted energy conservation policies. The major applications for this capability and the areas where the model's analysis is presently limited are indicated below.

a. Application to Household Energy Conservation Issues and Program Areas.

(1) Energy Pricing. In the model, change in fuel prices, either through government controls and taxes or through scarcity and market mechanisms, is one of several factors that enter the energy expenditure equations. These equations estimate purchases of the five different fuels as determined by a variety of household characteristics; some of these characteristics such as appliance fuel choices can themselves reflect the influence of fuel prices, given appropriate exogenous forecasts. Short-run price effects on the operation of existing appliances are modeled through short-run elasticities.

(2) New Buildings and Appliance Efficiency Levels. The model permits changes in input to the model in appliance efficiency levels and housing thermal performance as these are proscribed by standards or assumed to reflect household conservation preferences. Energy requirements can be varied by region, housing type, and year of change and then incorporated in the model through exogenously estimated rates (by income class when available).

(3) Retrofit of Existing Buildings. The model will stochastically distribute exogenous projections of the number of homeowners undertaking retrofit measures. The model can accept rates by housing type, income, and region and other household characteristics; and provide outputs for policy analysis to the extent that these average rates can be identified to occur as responses to specific retrofit incentives.

(4) Tax Credits and Rebates for Energy Efficiency Measures. Once the model has distributed the retrofit or new building energy efficiency measures, then the characteristics of the selected households can be used to calculate the tax credit or rebate appropriate for the investment and to indicate the changes in disposable income or net energy expenditures. Distribution of energy expenditures by disposable income provides a major welfare criteria for policy analysis.

(5) Appliance Ownership and Heating Fuel Choice. Changes in appliance ownership fractions and in fuel choices can be selected outside the model to reflect the effect of conservation policies, technological change, and relative fuel and equipment prices. These can be stochastically imputed to new or existing households according to specified income, housing type, and regional and other characteristics and the results used as inputs to the energy expenditure calculations.

(6) Specifically Targeted Conservation Programs. The high degree of disaggregation of MATH/CHRDS permits analysis of conservation programs or policies targeted to specific subgroups of the household population [e.g., retrofit of existing single-family residential buildings heated with fuel oil in the Northeast; or for conservation action taken for low-income households (weatherization)]. As currently structured, the model cannot address the conservation behavior of these subgroups. It can, however, stochastically attribute distributional detail for the exogenously projected average conservation response or actions expected for the subgroups.

b. Limitations to Current MATH/CHRDS Analysis. The current version of MATH/CHRDS is applicable for analysis of a broad range of energy conservation programs and policies, as discussed above. Its applicability, however, is lessened by various data and structural limitations. Several of these are listed below together with possible corrections or modifications.

(1) Explicitly Modeled Behavioral Effects. The present model structure depends heavily on exogenous projections of major variables which affect energy expenditure decisions. These include long-run adjustments, appliance efficiency, building thermal efficiency, fuels choice, and housing and appliance retrofit investments. There is value for policy analysis in having the analyst control the existence and extent of the interaction of various policies with individual behavior, but the potential complexity of these interactions and the level of MATH/CHRDS disaggregation argue against this as a

normal procedure, particularly where there is such a wide degree of potential long-run responses. Modification of the model to account for this would require detailed microanalytic estimates, but even estimates at a more aggregate level by income or housing type would assist in quantifying long-run adjustments in efficiencies and fuel to, for instance, price changes.

(2) Indirect Effects. The analysis in the MATH/CHRDS model is limited to the direct effects of energy policies on energy use. The model neglects changes in energy use which affect other energy and nonenergy-related consumption and income, and which in turn could affect further household energy expenditures. These indirect effects include:

(a) Long-run changes in efficiencies, fuels, and appliances as indicated in (1) above

(b) Trade-offs between services of energy appliances versus other goods and services and income in the home

(c) Changes in the prices or availability of nonenergy goods and services due to the energy inputs embodied in these

(d) Changes in household incomes and earnings due to energy-related purchases and employment.

Modifications to incorporate more of these effects are presently underway through EIA. A full accounting of these, however, requires a more detailed specification of all household consumption, not just energy-related services.

(3) Energy Expenditure Equations. The expenditure equations for each of the five fuels have not been strong predictors of energy use on a state-by-state basis. Errors are due to differences in data sources, definitions, sampling and reporting errors, problems in updating data for or imputing other estimates to variables of the expenditure equations, and weak specification of the equations. Some of this has been corrected in the 1975 data file by using more recently available surveys. Use of the National Interim Energy Consumption Survey (NIECS) may alleviate some of the data problems.

(4) Elasticity Estimates. The model explicitly represents only the short-run responses to changing incomes and prices. Long-run effects were addressed in

(1) above. The price elasticities also do not vary by income group. There now exist more disaggregated data with which to approximate these effects.

(5) Heating Fuels. Heating fuels choice is presently modeled as a function of observed housing trends and fuel conversions. This should be explicitly a function of at least relative fuel prices. Estimates for these on the aggregate level exist from Oak Ridge National Laboratories, or these could be reestimated specific to the model's purpose.

(6) Ownership and Use of Appliances. Average ownership rates are projected independently by the MATH/CHRDS analyst, and ownership for individual households imputed to conform to these rates. Similar to the analysis of heating fuels choice discussed above, appliance ownership should be the result of changes in income, prices, and other variables. Estimates are limited by data availability, but average cross-sectional data on ownership by various variables are available from NIECS.

(7) Building and Appliance Energy Efficiency Decisions. These are exogenous inputs for MATH/CHRDS. Analytical foundations for such choice at the household level are still under investigation, but MATH/CHRDS is very well suited to take advantage of this information when the data and research become more refined.

(8) Analysis of Renters and Master Metering. Initially MATH/CHRDS data for energy expenditures for renters were upward-biased by overreporting from renters that paid their own bills, and the estimates of energy expenditures for master-metered apartments were badly in error. Subsequent corrections in the 1975 data file have reduced these errors, but the model would still benefit from more updated benchmark data and estimates of renter behavior. NIECS will provide much of this on a cross-sectional basis.

(9) Statistical Limits on Disaggregation. MATH/CHRDS disaggregation is limited, as might be expected, by the size of the statistical sample for individual cells at the more disaggregated levels. This is particularly true for geographical information at the state level or below for specific combinations of household characteristics. Many of these gaps can be filled in with new Census level sampling.

(10) Updated Data and Files. MATH/CHRDS derives primarily from the 1970 Census Public Use Sample. This

is now projected and calibrated to 1975. More recent updates are important, particularly given the 1970 basis. Data from NIECS will be particularly valuable for this, both to provide behavioral data for calibration and to suggest changes in the basic distributions of fuels, housing types, appliances, efficiencies, household characteristics, and location.

B. The MATH/CHRDS Model Structure

1. Overview of the Model Structure

The MATH/CHRDS model uses a micro simulation approach to project a sample household survey by updating the demographic, socioeconomic, and energy-related household characteristics. Household energy expenditures vary as a function of energy prices, incomes, housing and energy-using appliance stocks, fuel choices, and energy efficiencies of appliances and structures. Distributional impacts of these variables can then be calculated for various conservation policy scenarios. Policy parameters include energy taxes, technological improvements in appliance efficiencies, thermal standards for structures, tax rebates and purchase credits, energy prices, and various changes in operational or behavioral energy-use characteristics.

The basic structure of the model derives from hierarchical micro data files on households which are assembled from merged base-year survey information on energy use, and on demographic, economic, and energy-related characteristics of individual households. These demographic, economic, and energy-related variables are then projected to provide elements of synthetic household survey records, as if obtained from a new (future) survey. Specific energy-using characteristics of each household are also updated to reflect exogenously determined aggregate national and regional changes in fuels use, appliance ownership and efficiency, and housing type, age, and location. Each household's energy expenditures for fuels can then be calculated from econometrically estimated parameters applied to such updated "survey" variables as cooking fuels, space- and water-heating fuels, number of rooms, type of structure, household size, appliance ownership, family income, price of fuel, and urban/rural location of the household.

Figure II-1 provides a simplified flow chart of the MATH/CHRDS model. The major elements of this are outlined below.

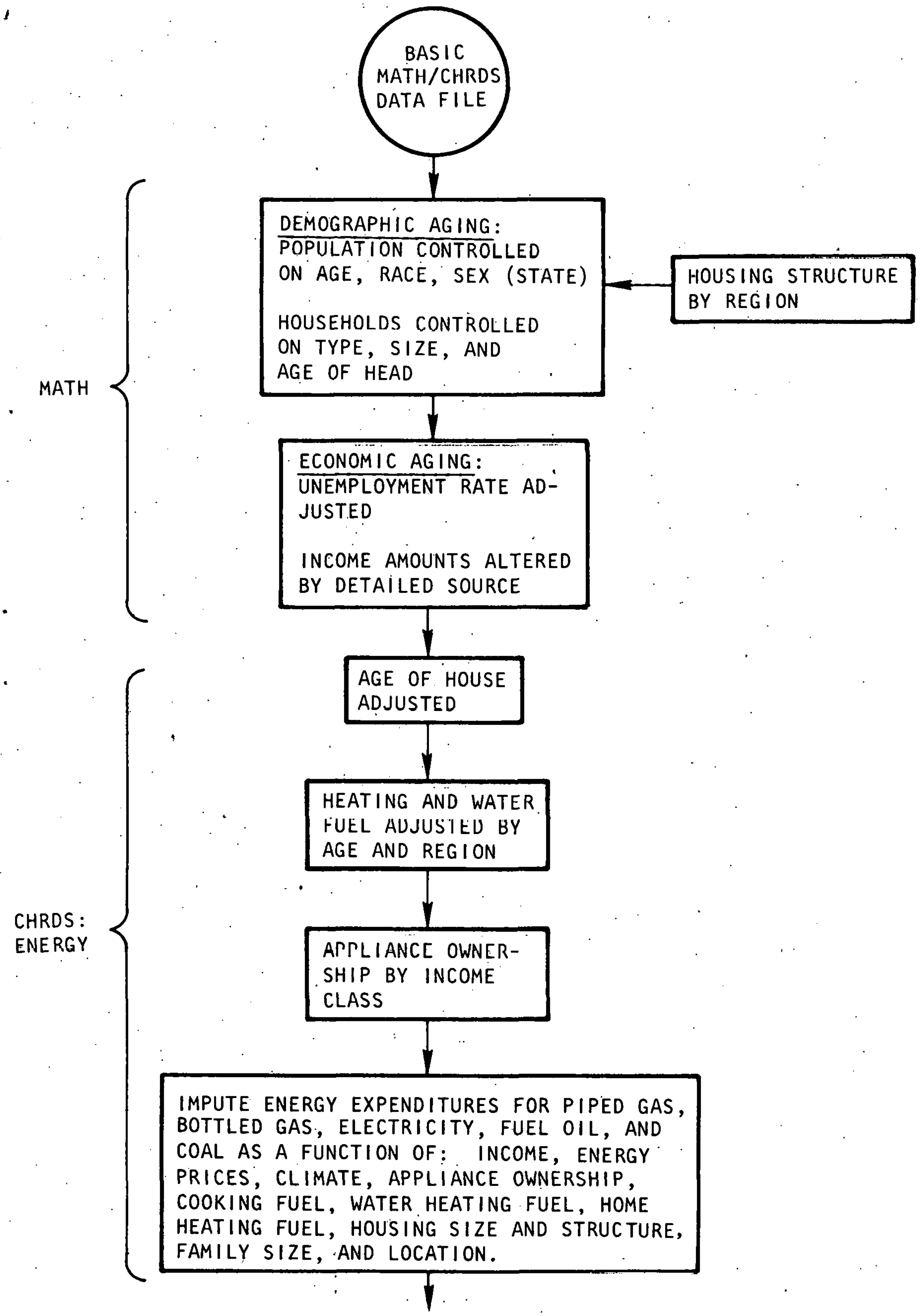
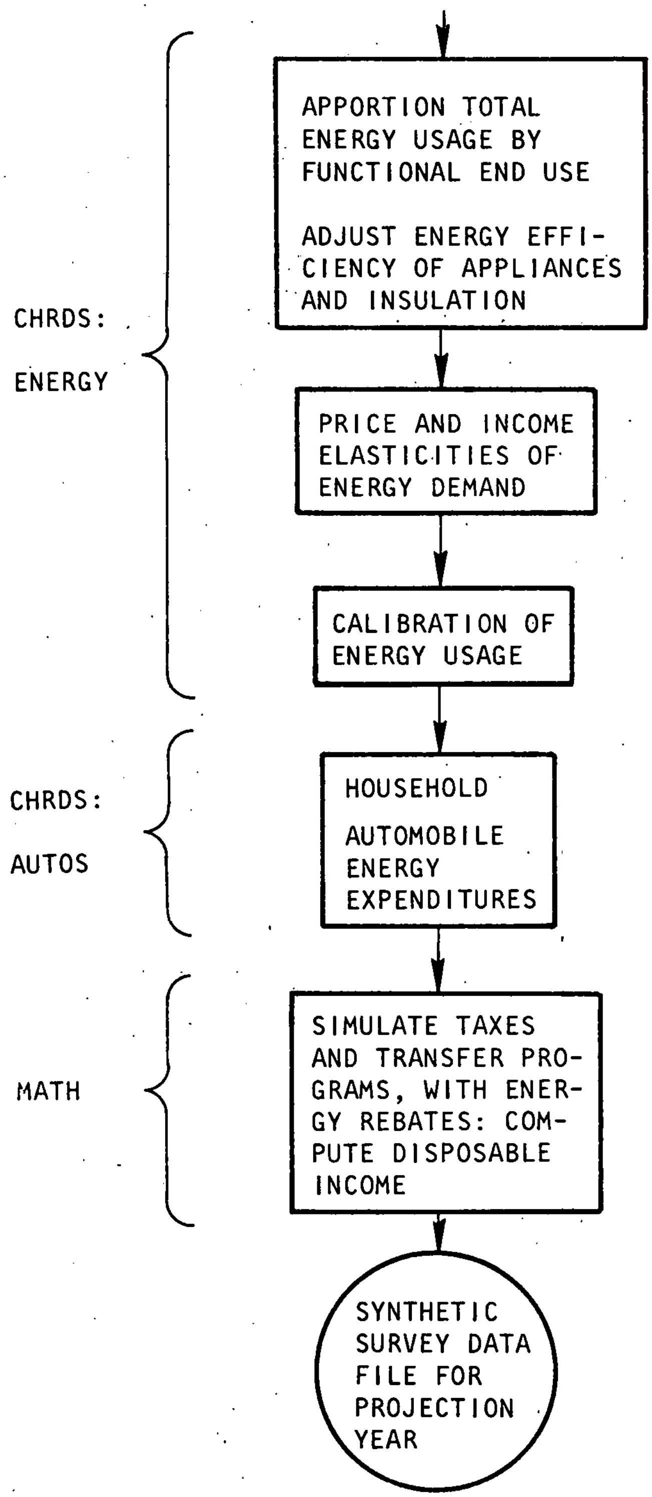


Figure II-1. Simplified Flowchart of the MATH/CHRDS Model



Source: Jill King. "The Distributional Impact of Energy Policies: Development of Application of the Phase I Comprehensive Human Resources Data System," Mathematica Policy Research, Inc., June 1977, pp. 9-10.

Figure II-1. (Continued)

a. Basic Data File and Data Base. MATH/CHRDS begins with the basic data file, a special subsample of 150,000 households from the 5 percent Public Use Sample of the 1970 Census of Population and Housing. This provides detailed information on demographic, socioeconomic, housing, fuel, and appliance characteristics of the households. The data are adjusted to impute energy expenditure information for renters and owners who did not report energy consumption information (including most importantly renters who do not pay their utilities separately). Imputation was by multiple classification analysis developed for a 1/1000 Public Use Sample. Transportation-related data from other surveys were also merged into the MATH/CHRDS file via a statistical matching technique.

The original MATH/CHRDS Data Base was a 1974 synthetic data base created by updating techniques on the basic 1970 MATH/CHRDS base file. Changes to develop this base and subsequent projections from the 1974 base are explained further in the discussions below. More recently an update to a 1975 data base was undertaken. This is discussed in Subsection 3 below. A 1977 file is completed but is not in use. A 1978 to 1979 file is contemplated for late 1980.

b. Demographic and Economic Aging of Data File. Probabilities for individual household demographic changes by age, race, sex, and location are distributed across the MATH/CHRDS file in a manner that develops the new demographic structure approximately equal to control totals from Bureau of Census population projections.

Similarly, changes in economic characteristics of individuals within the data file are also determined exogenously for 14 sources of income both by economy-wide employment-unemployment changes and by modifications to earnings trends. Taxes and transfers are then calculated based on dependents, parameters of the tax system, eligibility requirements, and, possibly, energy tax policies and credits.

c. Housing Stock and Fuels Use. The structure of the future housing stock is simulated to reflect exogenous macroeconomic housing forecasts of age and type of structure. Within the file, however, the relative position of residents with respect to age of their houses is held the same by varying randomly selected houses.

Changes in space- and water-heating fuels use for new and existing homes are assigned exogenously from Annual Housing Survey, Census Bureau Surveys of new construction and trends in home-heating fuel conversions. These changes are made for randomly selected households in the sample.

d. Appliance Ownership. Ownership rates are by income class for nine major appliances. These rates are exogenously specified and changes are randomly selected for households to conform to these specified rates.

e. Energy Expenditures. Home fuel expenditures for each MATH/CHRDS household are imputed from the updated demographic, socioeconomic, housing, and appliance characteristics of the households. Estimates are from an econometric analysis of the 1970 Census for each of five home fuels as a function of cooking fuel, space- and water-heating fuels, number of rooms, type of structure, household size, appliance ownership, family income, fuel source, and location.

f. Energy Efficiency Improvements. Adjustments are made to the imputed energy usage to reflect changes in appliance and structure energy efficiencies. The imputed energy consumption is first allocated to functional end uses (e.g., amount of fuel oil for home heating) so that efficiency changes can be directed to the specific energy use. Insulation, storm windows and doors, cooking, water heating, space heating, air conditioning, washing, drying, television, refrigeration, and lighting are differentiated by fuel use and by age of house, type of structure, and region. Changes in efficiencies are then stipulated according to policy targets or exogenous projections.

g. Income and Price Elasticity of Fuels Use. The model assumes that the long-run responses of fuels demands to income and prices are incorporated in the earlier specified changes in housing stocks and appliances in the projected fuel choices, and in the intensity with which these are used by households. Short-run income and price elasticities for each of the five fuels, however, can be further specified by income group, location, and other demographic variables.

h. Taxes, Transfers, Energy Rebates, and Disposable Income. The levels of energy expeditures can affect final disposable income of households depending on various energy-related taxes, rebates, or subsidies. A final step is to allocate these adjustments according to energy expenditures and income level characteristics so that the net distributional effects can be evaluated.

i. Calibration with Other Projections. Since MATH/CHRDS is often used with or driven by inputs from other energy forecast models (such as EIA's Midterm Energy Forecast System (MEFS) and the Macro Level ORNL Residential Energy Demand Model embedded in MEFS), this step permits calibration of the total energy consumption with these more aggregate national or regional projections.

2. The Analytical Techniques of the Simulation Model.

These techniques include:

(a) Introduction of stochastic factors to represent the random changes in individual behavior

(b) Systematic adjustment of randomly selected files to represent exogenous changes in demographic or economic conditions, or in housing stocks and appliance ownership

(c) Econometrically estimated procedures for imputing home fuel expenditures

(d) Markov-Chain stochastic processes to represent transitions in household status, e.g., employment and earnings changes.

3. 1975 MATH/CHRDS Data Base

The 1975 Data Base is the most recent data file available for MATH/CHRDS projections. This 1975 update was undertaken in part to assist development of a 1975 End Use Consumption Data Base (ECDB)*. Although the resulting ECDB was primarily an aggregation from the MATH/CHRDS file, it also required usage and expenditure by fuel and functional end uses that necessitated augmenting of the original Data Base.

The 1975 MATH/CHRDS file is essentially the demographically and economically aged 1974 Data Base adjusted for 1975 demographic, income, equipment, and housing stock data and for energy use characteristics. For this purpose, extensive use was made of the 1975 Annual Housing Survey. The data file was augmented with additional energy-related characteristics, using the 1975 Annual Housing Survey and the 1975 Washington Center for Metropolitan Studies Lifestyles and Energy Survey. These included:

(a) Air conditioning

(b) Insulation

(c) Storm windows

(d) Storm doors

(e) Black and white vs. color television.

*See Section F of *Major Models and Data Sources for Residential and Commercial Sector Energ Conservation Analysis* for a summary description of the 1975 ECDB.

1975 usage and expenditure were then imputed for each fuel using 1975 gas prices, weather data, and distributional demographic and income information. The resulting data base was then calibrated against industry control data.

The 1975 Data Base is in current use for EIA micro distributional analysis and for further projections and analysis from MATH/CHRDS (e.g., for the 1978 and 1979 Annual Report to Congress of EIA).

An excellent description of the 1975 updated Data Base is given in "Residential Energy Consumption by Functional End Use in 1975" (Jill King, 1979).

4. Sources of Data

The 5 percent State Public Use Sample of the 1970 Census on Population and Housing provides the special subsample of over 150,000 households for the basic MATH/CHRDS data file. This is augmented with energy data estimates from the 1/1000 Public Use Sample of the Census; the Consumer Expenditure Survey Series: Interview Survey, 1972, 1973 of the Bureau of Labor Statistics; the Washington Center for Metropolitan Studies (WCMS) Lifestyles and Energy Use Survey (1975); and the Annual Surveys of Housing of 1973, 1974, and 1975. 1975 appliance ownership and fuel characteristics are taken from WCMS and the Annual Survey of Housing. Imputation equations for fuel usage and expenditures were estimated from WCMS and the 1970 Census of Population and Housing data using determinants such as family size, size and type of dwelling, income and employment, appliance ownership, climate, housing characteristics, and energy prices. Data for fuel prices and sales by state are taken from the American Gas Association, the Edison Electric Institute, and the Bureau of Mines. The 1976 Survey of Income and Education provides updated data on employment and income for households in the data file.

5. Inputs

The MATH/CHRDS model has been initialized with a 1975 synthetic benchmark Data Base, which is itself an updated and modified version of the 1974 Data Base developed from the 1970 Census Public Use Sample and other Census Bureau publications. The 1975 updated Data Base rests heavily on adjustments from the 1975 Annual Housing Survey and the 1975 Washington Center for Metropolitan Studies Lifestyles and Energy Survey. Inputs to a model simulation are thus basically the updating and aging parameters for projecting the demographic and socioeconomic characteristics, the energy price scenarios for future years, appliance ownership rates, and housing start forecasts. Specifics of these are indicated below with potential input data sources.*

(a) Demographic - Census Bureau projection of population by age, race, and sex; Census Series B household projections.

(b) Unemployment Rate Adjustment - Projected unemployment and labor force from appropriate Data Resources, Inc., (DRI) forecasts.

(c) Income adjustment - Income growth rates by source of income over simulation period, from DRI.

(d) Tax Payments - Projected tax tables and payroll tax parameters for simulation years.

(e) Transfer Program Income - Eligibility standards and benefit levels by state and by program.

(f) Housing Stock Adjustments - DRI forecasts of housing starts and demolition rates; historical housing stocks by age from the 1975 U.S. Statistical Abstracts; fuel distribution for new and existing homes from the Annual Housing Survey.

(g) Appliance Ownership - Data computed by user.

(h) Energy Expenditures and Prices by Fuel, by State, or Region - For historical price data, American Gas Association, 1970 Gas Facts and other relevant years; Edison Electric Institute. For projected prices, DOE, Mid Term Energy Forecasting System (MEFS) projections, or other projection series.

(i) Elasticity Adjustment - Short-run price and income elasticities of demand supplied by user. Percent price changes over simulation period from MEFS.

Additional inputs are necessary for the transportation submodel.

6. Outputs

The output of the MATH/CHRDS model provides a simulated survey data file representing the effects on each household of proposed energy and energy-related changes. The output

*King, Jill. *The Distributional Impact of Energy Policies: Development and Application of the Phase I Comprehensive Human Resource Data System*. Mathematica Policy Research, Inc., June 1977.

file will contain the same variables as the input file, but updated and adjusted for demographic, socioeconomic, housing, and appliance projections and modified to reflect imputations of energy fuels expenditures. Excluding the transportation variables, these changes for each simulation year include:*

(a) Demographic - Population characteristics are altered to match control totals and to reflect changing demographic structure by age, sex, race, and location.

(b) Economic - Work experience variables and 14 basic types of income are adjusted to reflect changed conditions.

(c) Housing Stock Adjustment - Age distribution of housing stock, type of space heating, and water heating fuel are modified for each 10 housing types.

(d) Appliance Ownership - Ownership of nine appliances for each household is modified.

(e) Energy Expenditures - Annual household expenditures on electricity, natural gas, bottled gas, fuel oil, and coal are "updated."

(f) Elasticity Adjustment - Elasticity adjustments are made for home fuel expenditures.

Further description of specific output and results can be found in "Residential Energy Consumption by Functional End Use in 1975" (Jill King, 1979) and in EIA's Annual Report to Congress, 1978, Volume Three.

C. Applications and Extensions of MATH/CHRDS for Residential Energy Conservation Policy Analysis

The MATH/CHRDS model can simulate, at the household level, the distributed impacts of proposed household energy conservation policy and present these as a synthetic sample survey showing the effects on each household of the energy changes. The major impact variables are the distribution of household energy expenditures and fuels use as these are

*Brazzel, M., J. Hewlett, E. Reiser, and A. Silver, "A Distribution Analysis of the 1985 Energy Projections for the Annual Report to Congress of the Energy Information Administration," Analysis Memorandum AM/IA/78-09, (EIAC-DOE/EIA-0102/25), June 1978.

affected by changes in energy pricing in combination with changes in appliance efficiency levels, energy use patterns, and household demographic and socioeconomic characteristics. Household incomes may also be changed by the effect of energy tax rebates, subsidies, and transfers. For a given simulation, the resulting distribution of energy consumption can be compared across regional, socioeconomic, and income groupings. Changes in disposable income, energy consumption, and energy expenditures for these groupings can be assessed by comparing simulation runs with different assumptions about energy conservation policies. The discussion below details the relevant energy policy variables in the model and the issue and program areas to which they apply. (The Appendix to this report provides a discussion and partial listing to the DOE buildings energy conservation goal objectives and programs). Limitation of the existing model for policy analysis and suggestions for modifications or extensions to go beyond these are incorporated into the discussion of potential policy applications.

1. Policy Variables

The major energy conservation policy variables and parameters which can be applied to MATH/CHRDS simulations include:

(a) Regional- or state-level prices for the five home fuels: electricity, piped natural gas, bottled or LP gas, fuel oil, and coal. For the transportation sector the price of gasoline is also included. These are the primary policy variables of CHRDS.

(b) Changes in energy efficiencies of homes and appliances. There is, however, no present mechanism to endogenously simulate this behavior, although the model structure, with some modifications, is appropriate for this since individual households are identified by housing structure, age of house, income, and types of appliances.

(c) Probabilities of increased space heating fuel efficiencies due to increased use of insulation by type.

(d) Aggregate probability distributons for the existence of housing structures, home and water heating equipment, fuel switching, and cooking fuels. These would be entered as "net effect" policy variables to the extent that other more direct conservation programs and policies are estimated (through other models) to affect these distributions.

(e) Aggregate distribution by income, class of appliance ownership, and fuel usage for major applances: clothes dryers, automatic washing machines, wringer washing machines, food freezers, dishwashers, and televisions. Air conditioner ownership has also been added. Again, these would be entered as "net effects" policy variables to the extent that other more direct conservation policies are estimated to affect these distributions.

(f) Changes in energy-related subsidies, taxes, rebates, tax deductions, and overall tax rates.

2. Applications to Household Energy Conservation Issues and Program Areas

The MATH/CHRDS model, although a demand model in structure, is currently used primarily to simulate the distributional effects of various demand scenarios that are basically developed outside the model. Further examination of this, the limitations this places on policy analysis, and the modifications that could lessen these are given in Subsection 3 below.

The model nevertheless can play a very important role in energy conservation policy analysis by providing the major analytical tool to translate the energy demand scenarios into distributional impacts at the household level. By permitting the decision maker to assess the impacts of energy conservation policies on a household basis, the MATH/CHRDS structure forces the planner to examine a consistent set of fuel uses and expenditure characteristics for a large number of directly redistributive federal tax and transfer programs and indirect and potentially redistributive programs for energy pricing, energy efficiency, fuels choice and appliance ownership.

Distributional impacts means the effects presented in the model by a large number of stratifications of the household characteristics -- disposable income, age of head, poverty status, family size, geographic strata, housing type, employment, etc. -- by each fuel type used in the house as well as by total energy expenditures. In general, the most important and frequently requested analysis looks at regional, demographic, and income characteristics in terms of fuel consumption and expenditures and percentages of disposable income spent on those home fuels. The distributional effects of conservation policies are evidenced by comparing base case scenarios with those having altered policy variables.

Conservation issues and programs that are addressed with the current model include:

a. Energy Price Changes. These enter the model directly in two places.

(1) Energy Expenditure Equations. In the model fuel prices are a factor in the energy expenditure equations that estimate purchase of five different fuels used in the homes -- electricity, piped and bottled gas, fuel oil, and coal. These expenditures are selected from econometrically estimated equations as a function of the fuel price, the particular use of the fuel, the size and type of dwelling, family size, climate, income, and available appliances. The energy expenditures are then imputed to each household based on the individual housing demographic and socioeconomic characteristics.

(2) Short-Run Operational Effects. Short-run effects of fuel price changes are modeled as variations in the intensity of energy use of household equipment. This adjustment to prices is estimated using short-run elasticities of the demand for energy. Since the MATH/CHRDS model is used primarily with the EIA Midterm Energy Forecasting System (MEFS), these elasticities are generally chosen to be consistent with those used in the MEFS residential submodels.*

Long-run changes in energy usage due to price changes are not explicitly modeled in MATH/CHRDS. These are assumed to be reflected in changes in types of structure, home and water heating fuels, appliance ownership, and energy efficiency of the structure and appliances that are given from projection outside the model.

b. New Building and Appliance Energy Efficiency Levels. Changes in appliance efficiency levels and building thermal integrity can be accounted for in the model by changing the efficiencies of new and replacement appliances and the building materials and construction standards of new and replacement homes. For a model simulation, new homes can have new, more efficient appliances and improved insulation, where new homes are derived from exogenous projection of the residential housing stock. Lower energy requirements from better thermal performance are treated as a decrease in energy requirements for both space heating and water heating. These are varied by region, type of housing structure, and age of housing. Retirement and replacement are estimated from proportions of the stock purchased in earlier years. The proportions of the

See the discussion in Chapter I of this report of the elasticities used in the ORNL Residential Energy Model that are candidates for these short-run elasticities. The ORNL model is also the Structural Residential Energy Model of the MEFS' Regional Demand Forecasting System (RDFOR).

stock replaced are used as the probabilities for stochastically selecting households who retire and replace their appliances with more efficient ones. The replacement of appliances can be incorporated from exogenously estimated sales for each income class.

c. Retrofit of Existing Buildings. Exogenous projections of the number of homeowners undertaking measures such as wall insulation, ceiling insulation, caulking of windows, and installation of storm windows and doors can be used to estimate the proportion of houses of each building type by fuel type that have potential for retrofit actions. The proportion in each category can then be used as probabilities for stochastically selecting households to undertake retrofit actions. For these, heating and cooling energy requirements can be reduced by the average efficiency change estimated for each category.

d. Tax Credits, and Rebates for Energy Efficiency Measures. New purchases and retrofits such as discussed in b and c above can have taxes, tax credits, and rebates associated with them. The model does not use these incentives directly to calculate the numbers of potential conservation responses. These must be calculated outside the model based on estimates of the resulting energy savings, the price of the heating fuel, and estimates of the number of homes "in need."* However, once the conservation actions have been stochastically distributed to the households by housing, fuel, and (if data are available) income characteristics, then the model can use these to estimate -- specific to the selected households' characteristics (income, dependents, deductions, etc.) -- the appropriate tax credit or rebate, and the net change in disposable income.

e. Heating Fuel Choice. The choice of heating fuels for new homes and conversions of heating fuels in older homes are generally extrapolated outside the model from the fuel fractions in new homes built or existing in the historical period. The 1974 MATH/CHRDS data file used the Annual Housing Survey observations. By comparing the projected distribution of heating fuel with those in the base year, probabilities can be calculated to stochastically select houses in the model to change heating fuels for the projected year synthetic data file. These projections are by age of the house and by region. The MATH/CHRDS analyst can select changes in fuel choice for these projections that better reflect the effects of conservation policies on other outside influences such as fuel availability or changes in relative fuel prices.

*King, Jill. *The Distributional Impact of Energy Policies: Development and Application of the Phase I Comprehensive Human Resources Data System*, Mathematica Policy Research, Inc., June 1977, p. E-10.

f. Appliance Ownership. Similarly, appliance ownership rates can be specified by income class, and ownership imputed to new or existing households to conform to these exogenously determined rates. The choice of the ownership rates can also reflect the effect of conservation policies.

g. Specifically Targeted Conservation Programs. MATH/CHRDS provides a high degree of disaggregation of households -- for example, by 10 DOE regions (actually to state and county level, though not with statistical validity for many variables); by nine building types; by building age, structure, ownership, and metering characteristics; by household age, race, sex, and family size; by 14 income groups, and by five fuels. This permits analysis of conservation programs or policies targeted to specific subgroups of the household population. These might include, for instance, retrofit or new building standards for tenant-occupied residential buildings, retrofit of existing residential buildings heated with fuel oil, and retrofit of existing buildings owned and/or occupied by low-income households (weatherization). Though the model as currently available cannot address the conservation behavior of these subgroups, it can stochastically attribute the exogenously projected conservation changes to these subgroups so that the additional distributional detail of the data files can be linked to the target subgroups. Thus, the distributional aspects of broad-based weatherization grants to low-income households can be examined in terms of, for instance, regional and racial distribution, the change in energy expenditure as a proportion of disposable income, etc. Or if planners thinks one subgroup is more sensitive to a specific residential energy conservation information or to an audit program, then the model can indicate how that group is distributed across socioeconomic, demographic, geographic, and energy use characteristics and depict the hypothesized changes in energy use.

3. Extending MATH/CHRDS for Energy Conservation Analysis

The current version of MATH/CHRDS, although applicable for disaggregated analysis of a broad range of energy conservation programs, is restricted in its applicability and precision by various data and structural limitations. These are discussed below and, where possible, modifications or extensions of these are suggested.

a. Major Issues. There are two interrelated areas of the model which restrict its usefulness as a tool for analyzing residential energy conservation policies. These are:

(1) The heavy dependence on exogenous projection of important variables determining energy consumption

(2) The lack of analysis of the indirect effects of energy expenditure as they feed back into energy-related choices.

(1) Dependence on Exogenous Projections. The present structure depends heavily on exogenous projections of major variables which are themselves integral to the energy use decisions. Changes in appliance efficiency, building thermal efficiencies, fuels choice, and appliance and housing retrofit decisions are essentially all based on exogenously determined rates. As a result, these may not reflect changing fuel prices, capital cost, and energy savings incentives faced by the household over the projection period. The choice of heating fuels is determined endogenously in the model by trend data on new housing and replacement heating systems; it is not a function of price. The model response to price and income changes is reflected primarily in the short-run price elasticities. Long-run responses which should be found in changes in the fuels used and the stock of energy-using equipment are captured only insofar as the MATH/CHRDS analyst can foresee these in the exogenous forecasts. This may be due in part to the fact that the MATH and earlier TRIM system were originally designed, and still best suited, for short-run distributional analyses where the basic composition of the stock does not change significantly. As a result, for many aspects of the longer run analysis, the model in effect mechanically transfers (statistically imputes) given inputs and macro forecasts to the disaggregated household sector. While this disaggregation and the related statistical distribution of the effects can itself be valuable for policy analysis, the lack of a behavioral structure (except for those in the energy expenditure equations) does not encourage the analyst to take advantage of the richness of the individual household information in assessing the impacts of energy-related decisions.

Further discussions of appliance and housing efficiency, fuel choice, and the energy expenditure equations are included in b. below, together with possible modifications.

(2) Lack of Indirect Effects. The analysis in the MATH/CHRDS model is limited to the direct effect of energy policies on energy use. Thus, the model neglects changes in energy use which should affect other energy and nonenergy-related consumption and investments and also the income levels of individuals. These in turn could affect further energy purchase decisions. There are three related effects: Efficiency levels, fuel choice, and appliance purchases should be related to

their relevant energy costs and savings, as these are affected by relative prices of fuels and previous purchases and conservation decisions. To some extent this deficiency is discussed in (1) above. Rising energy expenditures should involve trade-offs with other goods and services that the household needs. Changes in energy-related taxes and incentives and transfers likewise should affect energy- and nonenergy-related decisions. Changes in energy conservation, prices, and availability of energy resources affect the prices of other goods and services which do not directly consume energy in the household, but which involved energy inputs earlier in their production (e.g., energy inputs embodied in agricultural products). Likewise, employment and incomes can be affected for those directly or indirectly involved in the production processes. Together these could play a major role in the choice and levels of household energy use. The net result of excluding analysis of these can lead to both incorrect projection of levels of energy expenditures and to altered distribution of the effects across individual households which are differentially affected by the feedbacks.

Modifications of the model to incorporate these effects are in fact presently underway at EIA and Mathematica Policy Research, Inc. Their approach is to develop a revised model that treats jointly the energy and non-energy goods decisions and to look at the direct and indirect effects of these in an input-output framework. This requires large amounts of data, some of which are available from other micro simulation surveys of consumer choice;* and some of which are embedded in further analysis of Census and expenditure survey tapes and some of which involves further development and adaptation of energy coefficients in national input-output analyses.

It is also possible to partially adjust the model to incorporate these feedbacks by developing procedures where the MATH/CHRDS analyst iteratively alters selected inputs where evidence from other modeling experience (e.g., per ORNL models) suggests likely interactions.

b. Additional Areas. Additional areas where the model might be improved include the following:

(1) Energy Expenditure Equations. The results of the energy expenditure equation are often found to be

*See, for instance, Orcutt, Guy, et al., *Policy Exploration through Microanalytic Simulation*, The Urban Institute, 1976.

weak and based on outdated information. Determinants of energy expenditure for each of five fuels were estimated from linear equations. The original FEA version of the model developed for the 1974 Data File used the Public Use sample of the 1970 Census for observations on individual households. This analysis identified as major determinants the reported use of each particular fuel, the size and type of dwelling, size of family, appliances, family income, fuel prices, location, and climate. A reestimate of these for electricity and piped gas was developed for the 1975 MATH/CHRDS file using the more detailed but smaller sample from Washington Center for Metropolitan Studies energy use survey (WCMS). The WCMS information permitted additional analysis on building thermal integrity and a wider range of family characteristics, as well as providing more up-to-date information.

The equations that were estimated, however, are not strong predictors of energy use. This can be seen in terms of the low multiple correlation coefficients ($\bar{R}^2$) of 0.72 for electricity, 0.43 for piped gas, and 0.34 for fuel oil and bottled gas for the 1975 estimates.* Though the elasticity and natural gas estimates from the later WCMS data are somewhat better, all of the equations leave a large portion of the energy expenditures unexplained. This is further confirmed by the levels of "calibration" factors used to adjust estimated MATH/CHRDS usage to the published average usage given by Edison Electric Institute, the American Gas Association, and the Bureau of Mines. On a state-by-state basis, these required an average 10 to 20 percent adjustment for electricity and piped gas; many of the factors were over 50 percent in the more difficult-to-measure usage of fueloil, kerosene, and bottled gas.

Errors in the model are due to a variety of problems: differences in data source definitions, different sampling and reporting errors, difficulties in updating and imputation to the later files, as well as weak specification of the expenditure equations. It would appear, though, that use of more recent and detailed data where available would alleviate much of the problem with the energy expenditure equations. The National Interim Energy Consumption Survey (NIECS) from the winter of 1978-1979 could be used to provide a broader and more detailed national sample than the WCMS or the Census data.**

*King, Jill. "Residential Energy Consumption by Functional End Use in 1975," November 1979, p. 34.

**See Hittman Associates, Inc., Section E, "NIECS," of Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis for a summary discussion of NIECS.

As indicated in a.1 and 2 above, the model does not necessarily reflect household energy-related responses in fuel and appliance choices, and in housing and appliance efficiency levels, nor does it provide feedback from energy exenditures to energy- and nonenergy-related consumption and income. Reestimation of the expenditure equations alone, therefore, will not fully correct the energy expenditure estimates.

(2) Elasticity Estimates. As discussed earlier (in subsection B1g and C3), the model explicitly represents only the short-run response to changing incomes and prices; long-run responses should also be incorporated in appliance, fuel choice, and efficiency decisions. The model also assumes as appropriate for the short run zero cross price elasticity, (or unresponsiveness of use of one fuel to changes in the prices of other fuels.) The actual price elasticities are taken from short-run aggregate residential-sector price elasticities used in EIA forecasts. The model does not, however, vary the price elasticities by income group (there is included an income elasticity, but price elasticity in the model does not itself vary by income). There is reasonable theoretical and empirical evidence indicating that the price elasticity should vary by income level.* For the original MATH/CHRDS model, there were insufficient data to estimate these effects, but cross-sectional data should now be available from NIECS, as well as from various utility-sponsored residential consumption surveys**. The model is easily modified should these income-related price elasticities be estimated.

(3) Projection of Heating Fuels. The choice of new heating fuels is based on continuation of observed trends in housing starts and conversions in existing homes, rather than behavioral variables. [The projected total fuel use proportions are, of course, altered in the model by the conservation policies which directly effect consumption of each fuel as well as the differential effect of this across socioeconomic groups. This is, however, different than the fuel choice (or switching) decision.] Principal among the omitted variables are the relative fuel prices. Changes in, for instance, the relative price of oil to electricity will affect the fuel choice for new homes and for conversions.

*For example, the results of Jerry Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables" indicate that consumers evaluate fuels and energy equipment costs differently depending on income level.

**For example, Bonneville Power Administration's "Pacific Northwest Residential Energy Survey, 1980."

Other studies exist which develop various aggregate econometric estimates of responsiveness of fuel market shares to changes in own and competing fuel prices.* To allocate these aggregate estimates to different income groups, housing types, and regions, the model could continue to use as a first approximation, the existing proportions; alternatively, market shares estimates by income and region could be used.**

(4) Ownership and Use of Appliances. Other than specifying growth trends of appliance ownership by income class, the MATH/CHRDS structure does not explicitly model ownership and use of appliances as they vary with income. Ideally, changes in individual ownership patterns should be the result of changes in income, prices, and other variables; instead average ownership rates for each appliance are projected independently by the MATH/CHRDS analyst, and ownership then imputed to conform to these rates. While this "adjustment to trends" procedure is also used for more aggregated residential energy demand models, lack of behavioral analysis in the micro simulation context loses much of the benefit of the micro detail; individual choice of energy-using appliance follows rather than leads the aggregate averages. At the present, however, use of such analytical methods to alter or modify this approach are limited by data; much of the data is not available for a product purchase pattern by income and relevant demographic/ economic information.# Data from the Midwest Research Institute (MRI) appliance use survey and from NIECS can provide cross-sectional information on appliance ownership, income, housing, and household characteristics which could suggest up-to-date appliance ownership behavior, though these would not satisfy the full specification requirements at the micro level.

Analysis of appliance use behavior by income is similarly lacking in the model. In this case, the data are very sparse, with major sources consisting of metering surveys such as that by MRI which had less than 60 sample points.

**See, for example, the fuels market shares estimates in Lin, Hirst, and Cohn. Fuel Choices in the Household Sector, ORNL/CON3. October 1976.*

***The Lin, Hirst, and Cohn estimates include an income variable. They have been reestimated by DOE regions in Sakalosky and Muttardy, State Residential Energy Demand Model, Version V, TetraTech, Inc., April 1979.*

#See U.S. Department of Energy, Energy Efficiency Standard for Consumer Products, Technical Support Document No. 4, DOE/CS-0169, June 1970, pp. 5-55 to 5-63.

(5) Buildings and Appliances Efficiency Decisions. Both fuel choice and appliance and structure energy efficiency choices should at least in part be the product of the consumers' comparison of the initial conservation investment costs to the resulting fuel savings. This decision process is not modeled in MATH/CHRDS. The analytical methods to develop this are in their early stages and much of the basic data is missing. The existing results do, however, suggest that these decisions will vary by income and socioeconomic classes.* The MATH/CHRDS is much better suited to take advantage of this additional disaggregated information than the more macro energy demand models. This disaggregation permits the model to select the candidate households and quantify the degree and number of conservation choices of new retrofits of existing residences. Advances in the field of discrete choice analysis and data collected from national and utility surveys should present better analytical structure and estimates of fuel and technology decisions. The MATH/CHRDS micro detail makes it probably the model best suited to apply such results toward analyzing the differential acceptance and implementation of energy conservation policies.

(6) Renter/Owner and Master Metering Effects. The 1970 Census file on which the basic CHRDS model was developed contained energy expenditure information only on those renters who paid their own utilities. Subsequent analyses of the 1974 MATH/CHRDS data file results, the Census Bureau's follow-up surveys, and the Midwest Research Institute's (MRI) master metering surveys have indicated that this strongly misstated energy expenditure by renters. Subsequent changes have been made for the 1975 data file to correct for two kinds of bias:

(a) Overreporting of energy expenditures by those renters who received direct billings. The Census Bureau found this to be from 25 to 50 percent too high.

(b) Higher usage of master-metered apartments. MRI found this to be an average of 35 percent higher

**Efficiency choice algorithms are incorporated in the ORNL Residential Energy Model in the form of minimum life-cycle calculations using engineering-defined capital-cost-versus-efficiency tradeoffs. Discount rates for this decision vary by end use. Studies by Hausman and others suggest that these discount rates also vary by income, class, and other socioeconomic factors.*

Correction factors for these biases have been undertaken for the 1975 file; the reporting bias was corrected in the file by distributing the error according to monthly rental expenditure level; the master metering bias, due to extremely limited data, was only corrected by a uniform distribution among all master-metered apartments. Although the resulting 1975 files for energy usage conform on average for all consumers more closely to updated benchmark data (see b.1 above), the extent to which these can be used for analysis of the specific renter issues is obviously limited by the lack of directly measured renter data and analysis of renter behavior. Again, the NIECS results for renters will provide more accurate information with which to more precisely benchmark and calibrate the files to 1979. The NIECS data will also help explain renter behavior (or at least behavior trends) in terms of fuel price response, appliance purchases, and conservation efficiency measures. The more accurate benchmark and behavior data will make the file useful for projecting future years.

(7) Statistical Limits to the Disaggregation. A given fact of micro simulation is that the level of disaggregation is limited by the lack of large enough samples to enable assignment of statistical significance to individual cells. This is particularly true for geographical information at the state level or below, and also for coal use at every level. Even with the very large Census Public Use Sample used by MATH/CHRDS, the sample size can be so small (for instance, for three-member households in a particular region that live in housing of a given type and age that have electric heating) that results could be biased by only a few mismeasured or extreme values. Furthermore, it does little good to have the additional model detail if there is no meaningful way to attribute change in energy use to those specific households. Since MATH/CHRDS has extracted about as much detail as would presently be worthwhile from the 1970 Census samples, added cells will have to await 1980 Census results. The results of NIECS and future follow-on rounds of the Residential Energy Consumption Survey (RECS) may be able to fill in some of the gaps for more detailed conservation measures.

(8) Updated Data and Files. MATH/CHRDS derives primarily from the 1970 Census Public Use Sample, as discussed in Section B above. Although the basic disaggregated detail of the file cannot be changed until the 1980 Census, there is a need to update the estimates. The procedure followed by MATH/CHRDS is to create a new updated file that has been corrected and calibrated to

the most recent information. While no detailed survey will be available to reestimate the individual household cells, comparisons of cell averages to more aggregate data can suggest changes in distribution of fuel use, housing type, appliances, and location that must have taken place. The original data file was a projection of the original 1970 base to 1974. This has since been updated to 1975, using the Annual Surveys of Housing and WCMS and MRI survey data. Given the changes in prices, conservation measures, and technologies that have occurred since 1975, the need for far more recent updates is obvious. Apparently, a 1977 file has been computed but not fully verified by EIA and Mathematica Policy Research, Inc. (A more important update will occur with the now-released tapes of the 1979 NIECS results).

D. Bibliography

American Gas Association. 27th Annual Survey, House Heating Survey, Gas Utility Industry, United States, 1974-1977.

Brazzel, M., J. Hewlett, E. Reiser, and A. Silver. "A Distribution Analysis of the 1985 Energy Projections for the Annual Report to Congress of the Energy Information Administration," Analysis Memorandum, AM/IA/78-09. (EIAC-DOE/EIA-0102/25). June 1978.

Citro, Constance F., and Douglas F. Bendt. Description and Evaluation of the SPACE Sample. Prepared for the Department of Health, Education, and Welfare, by Mathematica Policy Research, Inc., March 7, 1975. (State Public Use Sample).

Edison Electric Institute. EEI Statistical Yearbook, 1974. New York, 1975.

Hausman, J.A. "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables." Bell Journal of Economics, Vol. 10 (Spring 1979), pp. 33-54.

King, Jill. "The Comprehensive Human Resources Data System." Mathematica Policy Research, Inc., February 1978.

King, Jill. The Distributional Impact of Energy Policies: Development and Application of the Phase I Comprehensive Human Resource Data System. Mathematica Policy Research, Inc., June 1977.

King, Jill. "Residential Energy Consumption by Functional End Uses in 1975." Mathematica Policy Research, Inc., November 1979.

Midwest Research Institute. Patterns of Energy Use by Electric Appliances, EPRI EA-682. January 1979.

Orcutt, Guy, et al. Policy Exploration through Microanalytic Simulation. The Urban Institute, 1976.

U.S. Department of Commerce, Bureau of the Census. Annual Housing Survey, 1975, Current Housing Reports 150-75 (A+E), United States and Regions. U.S. Government Printing Office, 1977. (Note: These reports are available from 1973 to 1977).

U.S. Department of Commerce, Bureau of the Census, Construction Reports, Series C26-74 Supplement, "Characteristics of New Multi-Unit Residential Buildings." Washington, DC 1975.

U.S. Department of Commerce, Bureau of the Census. Current Population Reports, Population Estimates and Projections, Series P-25, No. 544, "Estimate of the Number of Households for States: July 1, 1973 and 1974." GPO, Washington, DC, April 1975.

U.S. Department of Energy. "Energy Efficiency Standards for Consumer Products - Economic Analysis, Technical Support Document No. 4, DOE/CS-0169. June 1980.

U.S. Department of Energy. Energy Efficiency Standards for Consumer Products - Engineering Analysis, Technical Support Document No. 5, DOE/CS-0166, June 1980.

U.S. Department of Energy, Energy Information Administration. Annual Report to Congress 1978, Volume Three, DOE/EIA/0173/3. Washington, DC, 1979.

U.S. Department of Energy, Energy Information Administration. "Residential Energy Consumption Survey: Characteristics of the Housing Stock and Households 1978," DOE/EIA-6207/2. February 1980.

U.S. Department of Energy, Energy Information Administration. "Residential Energy Consumption Survey: Conservation," DOE/EIA-0207/3. February 1980.

U.S. Department of Labor, Bureau of Labor Statistics. Consumer Expenditure Survey Series: Interview Survey, 1972 and 1973, Report 455-3, "Average Annual Expenditures for Commodity and Service Groups Classified by Nine Family Characteristics, 1972 and 1973," Table 1-b.

Washington Center for Metropolitan Studies. Lifestyles and Household Energy Use, 1973 and 1975 National Surveys (Tape). September 1977.

Washington Center for Metropolitan Studies. Survey of Household Energy Use, 1975. Final Report to the FEA, March 1976.

III. OAK RIDGE NATIONAL LABORATORY COMMERCIAL ENERGY MODEL

A. Introduction

The Oak Ridge National Laboratory (ORNL) Commercial Energy Model provides the analytical and quantitative structure that permits the user to assess the impact of commercial buildings energy conservation programs. Adaptation and application of the model at the national, regional, state, and (forthcoming) utility service levels have strengthened the model's position as a central tool for policy, planning, and program development both within the Department of Energy and for other federal and state authorities. The discussion that follows highlights the capabilities of this model and indicates how this potential might be extended for more precision and greater breadth of application in analyzing buildings energy conservation programs.

The background and outline for this study are discussed below and the results summarized. The chapter then presents a more detailed overview of the present model structure and applications and suggests refinements and modifications that should permit the model to be applied to an expanded list of energy conservation issues and programs for commercial buildings.

1. Background

The ORNL model has been in development over the last four years as a long-run simulation model to predict annual, national, and regional commercial fuel demand and energy use to the year 2000. The principal purpose of the model is to assist public and private sector decision-makers in planning and evaluating the impacts of buildings energy conservation strategies and policies. To do this, the model provides disaggregated commercial energy use information by four fuels, ten commercial subsector (building) categories, and five end uses. Forecasts for each of these building, fuel, and end-use combinations are determined in response to changes in: fuel and equipment prices, building stocks, growth and composition of the commercial sector, building thermal performance, appliance efficiency requirements, and usage factors that represent commercial-sector energy-use decision making. The model is thus sensitive to major demographic, economic, and technological determinants of commercial energy use.

Two versions of the model are being extensively applied: a national and a regional version. The national version provides annual forecasts of commercial-sector energy use in the aggregate. The regional version provides annual forecasts of energy use for the commercial sector for each of 10 DOE regions and forms the basis for the commercial energy demand of DOE's Regional Demand Forecasting System (RDFOR) of the Midterm Energy Forecasting System (MEFS). The model is available at EIA independent of RDFOR as the "Structural Commercial Energy Use Model." Additional versions of this model are nearing completion that will provide annual forecasts for analysis of commercial-sector energy use at the state level; utility-specific adaptations are under consideration.

Results of these national and regional versions are used as inputs to assist the evaluation of DOE commercial-sector energy conservation programs and proposed policies. These assist analysis of the influence of such factors as: building structure and appliance energy efficiencies, installation and equipment costs, energy pricing, location, and public grants to upgrade energy use systems.

The model's development is an ongoing process both at DOE and ORNL and at various other national laboratories and state planning organizations. The basic structure is outlined in two documents: Jackson and Johnson, 1978, Commercial Energy Use: A Disaggregation by Fuel, Building Type, and End Use, which describes data development; and Jackson et al., 1978, The Commercial Demand for Energy: A Disaggregated Approach, which gives the model structure. Subsequent engineering and econometric studies have significantly strengthened structural equations and parameter estimates of the original model.*

The analysis presented in this report is based on a review of the model's documentation and programs and discussions with the authors of the model, ORNL scientists, EIA and DOE planning and program staff, and other users of the model.

2. Outline and Scope of the Study

Both in its use by EIA for energy forecasting and in its applications within DOE and at ORNL for conservation program planning and policy development, the ORNL Commercial Energy

**Additional summary information on the model's structure, policy variables, inputs, outputs, data sources, specific versions, and accessibility is given in Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, Hittman Associates, Inc., 1980.*

Model has proved a valuable tool for analyzing a wide variety of energy conservation programs. At the current state of development, however, there remain limitations on the model's capabilities to analyze certain energy conservation program areas. Also, the model's base case against which these policies are compared can be improved by refining its data and structure. This chapter highlights some of the properties and current applications of the model and identifies several possibilities for improvements or modifications that may strengthen and broaden its future applications. These are intended to alert policymakers and planners to the model's capabilities and to suggest extensions that may help guide its future role in commercial energy conservation analysis. The results of this are summarized at the end of this section.

The major sections that follow present the more detailed examination of these findings. Section B provides an overview of the model structure and introduces the major variable and analytical elements of the model. This is sufficiently detailed to provide a reference for the later discussion and to identify the primary source documents. For the reader who is well acquainted with the ORNL Commercial Energy Model, this section may be omitted. The current major policy analysis applications of the ORNL Commercial Energy Model are outlined in Section C. These applications are introduced both to alert the user to the present model potential and to provide the basis for understanding the suggested additions. Section D then indicates extensions of the model that would enhance its potential to address additional commercial-sector energy conservation issues and to increase the precision of several existing applications. The discussion relates these directly to the model's analytical structure and data and suggests modifications, additional research, estimates, and data that would alleviate many difficulties.

3. Summary of Findings

a. Current Applications of the ORNL Commercial Energy Model. The model has been applied to at least seven major areas of energy conservation analysis. These are discussed below.

(1) Building Energy Performance Standards for New Buildings. The model computes the impact of building energy performance standards on energy use for space cooling, water heating, and lighting. The model accepts as input by building type, end use, and fuel, the minimum fraction efficiency improvements for new buildings (in energy use per square foot) that would occur when standards are implemented. The model then calculates material and installation costs relevant to

these efficiency levels and compares these to the simulated changes in fuels demand for each of the four end uses by building types.

(2) Standards for Energy Efficiency in New Commercial Appliances. In a similar fashion, the model accepts constraints on minimum efficiency improvement for new appliances and for replacement appliances. The model simulates the resulting reduction in commercial energy consumption and the corresponding appliance investment costs according to its minimum life-cycle cost criteria.

(3) Building Retrofits - Schools and Hospitals Grants Programs. The model computes the impacts of federal programs to grant funds to schools and hospitals for energy conservation investment. For given level of funding per square foot, the model computes the achievable efficiency increases. From these, the fuel savings can be calculated with respect to the base case.

(4) Investment Tax Credit. The tax credit effect on capital costs of conservation equipment permits the model to simulate cost-effective purchases of higher-efficiency equipment. Equipment expenditures and fuel savings from lowered operating purchases are computed for each fuel, end use, and building type.

(5) Conservation Technology Research and Development. The model can simulate the effect of these by assuming expected changes in capital costs of conservation investments and reduced efficiency limits. For new buildings and equipment, lower operating costs relative to capital costs encourage investments in higher efficiencies. Energy savings and new investment costs are calculated by comparing simulations with and without the R&D effects.

(6) Low-interest Loans. The effects of low-interest loans are simulated by reducing the discount rate used in comparing present capital costs versus future energy saving in energy-conserving buildings and equipment decisions. More energy-efficient investments at higher capital costs are thus cost effective according to the model's minimum life-cycle cost criteria.

(7) Fuel Price Modification. Changing energy prices have three effects on the model's results: They change fuel market shares for new construction, they change efficiency of new buildings and equipment, and they change the energy use in buildings to reflect

revisions in building operating practices. These then result in altered energy demands by fuel, building, and end use.

b. Extensions and Modifications of the ORNL Commercial Energy Model for Energy Conservation Analyses. Although current versions of the ORNL Commercial Model are applicable to a broad range of energy conservation topics, as evidenced above, the model's use could be enhanced in several areas. Extensions of the model through various modifications of the structure and by reestimations from new data sources could further increase the model's potential to assist policy planning and evaluation of commercial-sector conservation.

The following 11 topic areas were selected, given the model's basic capabilities, as areas where extensions, modifications, and applications of the model would be of significance in meeting DOE objectives for future commercial energy conservation planning and policy analysis. (See the Appendix to this report for a discussion and outline of these DOE objectives.) The topics embody both refinements in the existing model structure and substantial modification that would permit the user to better address key conservation issues and policy variables. In many cases the suggested refinement or modification gives only a possible direction for further work. Justifications for these are given in Section D of the text.

(1) Retrofit of Existing Commercial Buildings and Their Appliances for Higher Energy Efficiency. The current model only computes the impact of federally funded retrofit for schools and hospitals. For these buildings the model accepts expenditures per square foot for these retrofits and computes conservation investments using the capital cost versus efficiency technology characterization function to relate expenditures to equipment choice. This procedure could be extended to other building types. Unless the model endogenously models retrofit decisions, it is likely that the results will overlook responses to less explicit but ongoing incentives to retrofit embodied, for example, in tax rates, fuel prices, and changing technologies. A first step toward this would be to alter the model to accept the numbers and relative efficiency gains from retrofit decisions estimated outside the model. More explicit modeling might involve dividing buildings and appliances into separate fractions whose characteristics suggest their applicability to retrofit.

(2) Operational Conservation Measures. The model currently simulates the influence of higher energy costs

on the operation of equipment; but it does not provide for direct simulation of the impact of mandated operational conservation measures such as thermostat setback, reduced hours of operation, or delamping. To modify this, the computer code could be reprogrammed to accept a maximum utilization for each affected end use. This maximum would be an engineering estimate of the change in energy use due to the operational change (e.g., the Btu/ft^2 reduction due to a 5° lowering of the space heating thermostat after hours).

(3) Rate Structure and Load Management. The model accepts input forecasts of average annual energy prices by fuel type and computes commercial-sector demand on an annual basis. The same fuel oil prices are applied to each end use. Because of this, the model cannot be used to evaluate the impacts of rate structure policies. Similarly, the model only calculates annual energy use so that it cannot be used to evaluate load management programs. Modifications to the model to continuously reflect changes in rate structure and load management would be extremely difficult. However, approximation of the effects of a specific national or regionwide rate change is possible. Given changes in rate structure and load management practices since the model was originally estimated, reestimation for average effects of the new rate structures would be useful even if there are no other modifications.

(4) Alternative Energy Supplies - Solar Space and Water Heating. These are not currently represented in the model. With appropriate data, the technology characterization functions could be modified to accept these options, though the output would only reflect the utilization of the backup fuel. Much of the data and analysis for this currently exist in the solar market development and penetration models sponsored by DOE.

(5) Alternative Energy Supplies - District Heating. The model currently calculates consumption of electricity, natural gas, fuel oil, and other (primarily propane and coal). It does not currently simulate the use of steam for district heating (used primarily in large commercial buildings and shopping centers). To explicitly treat this in the model, market shares of space heating fuels would need to be modified to include the fraction of commercial buildings where district heating is available; the market share elasticities would need to be developed; the model would need to be modified to accept the prices for steam; and the technology characterizations would need to be augmented.

Presently data for these are weak or location-specific, and modeling even at the regional level would only be a rough approximation.

(6) Energy Conservation in Federal Buildings. The analytical structure of the ORNL model, with the modification suggested in (1) above, is well suited to simulate exogenously calculated target efficiency increases for new buildings and retrofits for existing buildings. The model, however, does not explicitly identify a federal building category, and federal buildings themselves differ widely in type and energy use characteristics. Retrofit modifications require procedures to accept input estimates of the fraction of federal buildings in each building type and the potential percent change in efficiency for each. For new federal buildings, the fraction of new floor space by building type would identify the federal portion of net savings from a mandated efficiency reduction. Existing energy use data on federal buildings, including that allocated for FEMP, are still very weak and limit more precise analysis.

(7) Energy Conservation in State/Local/Institutional Buildings. The model can simulate the impacts of a grants program for schools and hospitals. However, these and other buildings are not categorized separately in the model by state and local buildings. Data on energy use in state and local buildings, however, are more available than data on federal buildings. Simulation capability would require modifications of the model to accept an input efficiency reduction by building type along with the fraction of each building type affected by a state/local program only. This would apply to retrofit programs. Programs for new buildings can be incorporated in building efficiency standards if the new floor space fractions are known.

(8) Analysis of Renter-Landlord Effects. The present model does not differentiate buildings by owner or by billing characteristics. Conservation incentives appear to vary by these classifications. Data suggest that both ownership and billing characteristics vary significantly by building type. Modification of the model to accept discount rates that vary by building type would permit measures of behavior that could reflect the proportion of ownership, and the proportion of occupants that pay their own bills.

(9) Utility Activities. Many energy conservation activities mandated or voluntarily undertaken by utilities are only partially amenable to analysis with the present model structure. These include: energy audits

and energy information programs for commercial buildings, standards for new commercial utility customers, changing rate structures, district heating, prohibitions on new electricity uses, load management programs, and utility voltage reductions. More explicit modeling of these is summarized in 1 to 8 above. Additional modifications might need to incorporate fractional effects for specific utility service areas or would require modeling at the utility level.

(10) Regional Energy Use and Conservation Activities. The ORNL model has been disaggregated to make regional projections at the federal and state levels, and for three regions within New York State. These rely heavily on the national model structure with data inputs from the specific regions. Improvements needed to more accurately differentiate regional responses and impacts include: regionally estimated technology coefficients (efficiency versus capital cost) for individual commercial building types and end uses, and regionally estimated fuel market shares and equipment utilization elasticities. Also, though a state-level commercial energy model has been developed and state-level information has been found important to the progress of various conservation efforts, the state-level model has not received wide support for EIA and state adaptation and applications.

(11) Technical Improvements in the Structure of the Base Case of the ORNL Commercial Energy Model. Specification of the model's base case could be improved by refining some of the coefficient estimates and input data. These include:

(a) Updated technology characterizations of building thermal performance and equipment efficiencies

(b) Revised estimates of energy use per square foot by end use, fuel type, and building type

(c) Reassessment of commercial sector behavior toward fuel choice and investment decisions, fuel market shares, the discount rate, and equipment efficiency choices

(d) Revised specification of the equations for floor space additions

(e) Expansion of the number of building categories

(f) Revised estimates of equipment decay rates

(g) Reassessment of oil and gas usage simulations, given the errors found in validation exercises.

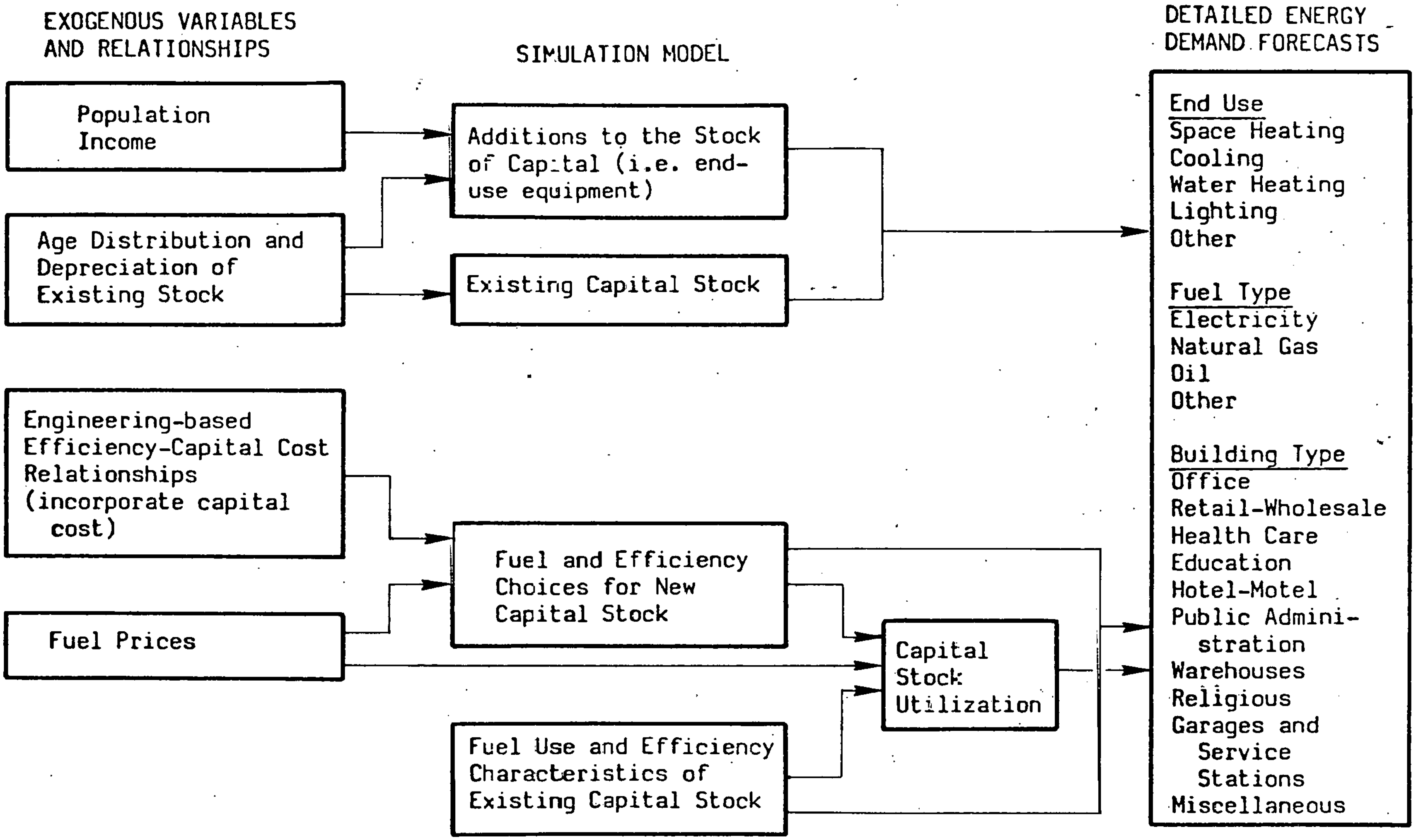
B. Basic Model Structure

1. Overview

The ORNL model uses an economic-engineering end-use approach to forecasting commercial energy use. The model employs a capital-stock analysis which explicitly recognizes that energy is consumed by capital goods (buildings and appliances) in the commercial sector to provide services (as warmth, business needs). Detailed engineering estimates of energy use by equipment, building structure type, fuel type, and age of capital stock are used to develop a disaggregated model of the commercial demand for energy.

Figure III-1 provides a schematic of the ORNL Commercial Energy Model. Input forecasts of income and population are used to predict the building stock, by building type. This stock together with building decay rates and stock history are used to estimate total new construction. Energy prices and input market share model coefficients determine the share of new construction and new equipment using each fuel for space heating. Given the equipment prices, technology characterization functions relate these initial capital costs of equipment to energy use to determine the energy efficiency of new construction and equipment based on voluntary choices; efficiency may also be modified by conservation programs. Energy prices affect the quantity of energy consumed by modifying the frequency with which energy-using equipment is operated. The model predicts fuel use by four fuel types, ten building types, and five end uses. Summing fuel use over building types and end uses gives total commercial consumption, by fuel type.

The basic model structure assumes that energy demand in commercial buildings in a given year is the product of the stock of energy-using equipment and the rate at which the stock is utilized. The stock of commercial building floor space is used as the proxy variable for energy-using equipment. The equipment is then defined in terms of the fraction of floor space that uses specific end-use equipment, and the



Source: Jackson, J. "Conservation Policy Modeling Capabilities of the ORNL Residential and Commercial Models" (Draft) February 1980.

Figure III-1. Schematic Representation of the Commercial Energy Demand Model energy use per square foot of floor space for each equipment type. Further precision is gained by disaggregating the floor-space stock by building type and age.

In algebraic terms, this energy use or demand is described as:

$$Q_{ijk} = \sum_{t=to}^{T} (UP_T)^t_{ijk} \cdot e^t_{ijk} \cdot a^t_{ijk} \cdot A^t_j \cdot d(T-t)$$

for fuel type i, building type j, end use k, at time T. Energy use in the commercial sector for building j in a specific case year T is described as the product of five variables:

$U_{ik}(P_T)^t$	Utilization rate of equipment of a given year t vintage as a function of energy prices in the P_T case year
e^t_{ik}	Potential energy use required per square foot of building by equipment of a given year vintage (the equipment efficiency)
a^t_{ik}	Fraction of floor-space additions in a given year served by each fuel and end use
A^t	Commercial building floor space added in a given year
$d(T-t)$	Fraction of floor-space additions in a given year which are still standing in the case year.

The resulting energy use in the commercial sector, Q^t given in Btu, is therefore determined by fuel prices, energy use requirements (Btu/ft^2), and net commercial floor space additions (ft^2). An energy use index is developed to estimate energy use requirements in commercial buildings by fuel type and end use. The utilization rate U^t (P_T) (which is a function of fuel prices) and potential energy use requirements for a given year are then measured relative to the utilization rate of the equipment for an arbitrary base year. The net fuel and equipment shares of commercial floor-space additions are estimated based on assumed fuel-price elasticities and the additions are estimated as a function of population and personal income.

Given the floor-space additions and their resulting energy use requirements, the model provides analysis of final energy demands in terms of equipment and structure efficiencies and fuel price elasticities. Choice of efficiency levels of new space heating and cooling systems depends on the trade-off between initial (purchase) cost and operating cost (fuel price and efficiency) of the new equipment, weighted by the commercial establishment's discounting of the future energy savings. Engineering descriptions provide the technical/cost possibilities for the space conditioning systems. Efficiencies of other equipment and appliances are determined by econometric estimates of the fuel price/efficiency responses.

The actual equipment utilizations are modeled as a function of both the fuel price changes and the efficiencies with which the equipment can be run. In the short run, the efficiency levels are fixed for existing equipment so that short-run utilization is a function only of energy prices.

Over the longer run, the equipment utilization is actually determined as a function of the cost of the end-use service produced by the equipment, and thus as a function of fuel prices weighted by the efficiency with which the equipment uses that fuel. Choice of equipment efficiency is itself described as a function of fuel price (and technology options, initial price, and discount rate for space conditioning), as described above. The analysis is similar where there is the added possibility of fuel choice. Thus, final energy demands are modeled as a series of interrelated decisions on capital stock choice (efficiency) and utilization (fuel price and efficiency) combined with short-run behavior responses to price.

The estimates of utilization, efficiency choice, fuel choice, floor-space stock, and building and equipment replacement are discussed in more detail below.

2. Utilization Rate

$U_{ik}(P_T)^t$ is the relative utilization of energy-using equipment of age t as a function of efficiency-weighted energy prices in the forecast year T. The efficiency weighting implies that the commercial consumer is purchasing the energy for the services provided by the energy-using equipment; equal changes in prices and efficiency should leave the price of the service, and thus the utilization, the same.

In the short run, fuel choice and equipment are fixed and the only utilization response is to vary operating procedures of the building and equipment. Thermostat setbacks, lighting cutbacks, and fewer open windows are examples of this. The model measures this price elasticity as the short-term elasticity of fuel usage. This is estimated by the first-year response of a commercial fuel use versus fuel prices econometric estimate. This estimate, found in Cohn, 1978, used 1968-1972 state cross-sectional data adjusted for errors in definition of the commercial sector and measurement of petroleum use for that sector alone. The longer-run elasticity coefficient is the same, but since fuel and equipment investments change efficiencies, the net prices of energy services will be smaller.

3. Energy Use Indices

The $e^{t}ijk$ measures the potential energy use per square foot required for equipment of age t. As such, these are measures of the efficiency of the equipment that commercial enterprises choose to purchase. For equipment other than the HVAC equipment, the efficiency choice in response to a fuel price change is estimated to be equivalent to the long-run fuel use adjustment to prices, after netting out the short-run operational responses. In the long run, equipment investments as well as utilization respond to prices. Thus efficiency elasticities are calculated as the net long-run usage elasticities. These elasticities are part of the previously cited usage elasticity estimates (Cohn, 1978).

For HVAC equipment, the efficiency and equipment choice are modeled differently. Combinations of capital cost and equipment efficiency for a given fuel type are estimated from engineering analyses which yield results similar to Figure III-2. In the model these curves are represented in the form

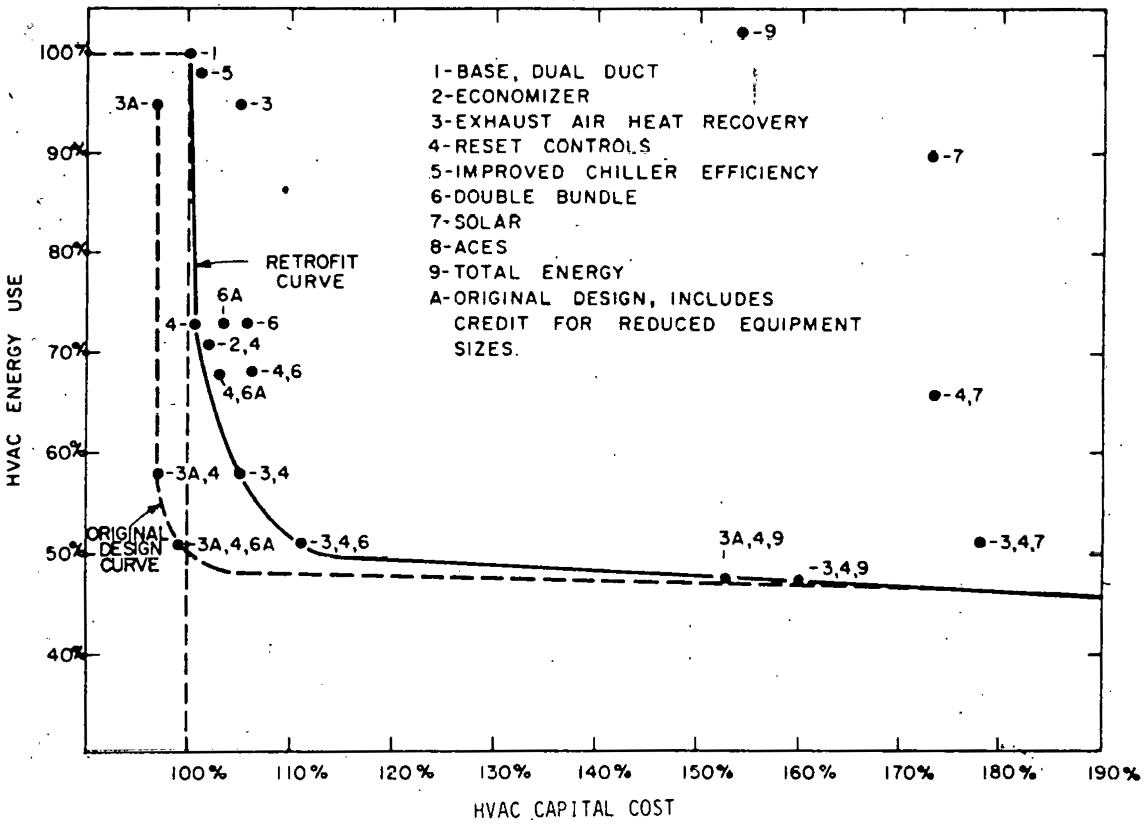
$C = \frac{b-\ln(E-a)}{d} - 1$, where C is capital cost, E is energy use,

and a, b, and d represent initial and asymptotic efficiencies. These, together with the fuel price and an appropriate commercial-sector discount rate, are sufficient to calculate the life-cycle cost of purchasing and operating the equipment. The minimum life-cycle cost combination of efficiency (or operating cost) and capital cost indicates the optimum equipment choice. The actual market choice differs from this optimum by a given factor that represents market imperfections.

4. Fuel Shares

The fraction of floor space allocated to a particular fuel and equipment, $a^{t}ijk$, is calculated from fuel share price elasticities estimated by Cohn, 1977, from the same 1968-1972 state data used in the fuel usage elasticity estimations. Since fuel switching occurs only as a long-run response to higher fuel prices, the short-run or one-year responses are netted out to give the fuel choice effect.

ORNL-DWG 78-9861



Source: J. Jackson, An Econometric - Engineering Analysis of Federal Energy Conservation Programs in the Commercial Sector, ORNL/CON-30, Oak Ridge National Laboratory, January 1979.

Figure III-2. Energy Use Versus Capital Cost for a Typical Office Building with a Dual Duct System

5. Floor Space

The stock of floor space is estimated as the sum of floor-space addition each year less those that are lost to demolitions or abandonment. Estimation of the stock for each year is necessary in order to detail equipment and energy use corresponding to the floor-space vintage.

Calculation of the historical building floor-space stock series was a major undertaking during the initial model development. For this, data on building starts from F.W. Dodge Construction Potentials for 1925 to 1970 were adjusted to meet the model's commercial buildings and U.S. regional definitions. An estimate of the stock in 1925 (recent versions use 1931) and a 45-year building life logistic demolition curve then permitted the annual stocks to be accumulated.

Additions to the stock of floor space in the past 1970 and the forecast years are estimated by econometric estimates of total commercial-sector floor-space requirements by building type. Major determinants of commercial output (and thus floor space) were found to be per capita disposable income and population. Additional commercial-building-specific factors, such as school enrollment for education buildings, were included where indicated by their statistical importance. Floor-space additions for a given year are then calculated as total requirements in that year less the stock of the previous year, less the demolitions calculated from the logistic decay function.

6. Building and Equipment Replacement

The model assumes that both buildings and equipment are removed from use according to their estimated lifetimes. All commercial buildings are assumed to decay according to the fraction still standing, $f(t)=1 - \frac{1}{1+\exp(6.91 - 0.1536\ t)}$ for buildings of age t. The average building lifetime implicit in this function is 45 years.

Equipment is assumed to have a fixed lifetime of 18 years, at which point all such equipment is retired.

7. Policy Variables and Parameters

a. Short-run. The primary policy variable which operates in the short run (one year) for the ORNL Commercial Model is the price of energy. Thus, short-run fluctuations in the demand for energy as a result of energy price changes are expected to include only behavioral changes, such as resetting thermostats, changing ventilation levels, and removing light bulbs, which reflect a change in the intensity of utilization of the present system.

Fuel prices can be affected through regulation or price decontrol policies and through tax policies, such as utility tax rates or oil import taxes. Policy options which yield short-run changes in demand for energy (i.e., the utilization rate) are limited by the ability to directly or indirectly alter energy prices and the short-run elasticity of energy demand, where the opportunities to respond to price changes are again limited to utilization changes with the existing stocks.

b. Long-run. The primary policy variables which operate in the longer run for the ORNL Commercial Sector Model include the following:

(1) Absolute and relative fuel prices

(2) Levels of equipment and building energy efficiency

(3) Relative price of capital and energy.

Absolute and relative fuel price changes affect commercial-sector demand primarily through the fuel price/efficiency trade-offs and elasticities for new equipment purchases and the equipment utilization elasticities of efficiency-weighted prices. Changes in absolute fuel prices can be accomplished through regulatory and tax policies, as mentioned above. The model properly reflects that the responses to these policy options are less limited in the long run than in the short run, because the longer time period allows changes in investment to occur, such as investing in more fuel-efficient equipment or conservation devices. Changes in relative fuel prices can be accomplished through similar policies which are fuel-specific. The model response in this case would be to alter the fuel mix, or the fraction of floor space served by each fuel. The opportunity for this type of response is also greater in the long run than in the short run, as long-term investments may be undertaken which result in fuel switching.

Changes in the level of equipment energy efficiency can be accomplished through the ORNL model by altering the energy use index (EUI) variables which reflect the specific technological trade-offs. Examples of such changes are buildings energy standards which alter the energy efficiency of the building envelope, and appliance efficiency standards which affect the energy use of water heaters, space heating or cooling equipment, and lighting fixtures. The long run affords the opportunity to invest in such conservation measures, and the model can estimate the impact of these conservation policies.

Changes in the relative price of capital and energy can involve the policy variables of fuel price and/or the purchase price for equipment energy efficiency levels. Altering these variables differentially can demonstrate the effects on conservation of substituting more energy-efficient capital stock for energy use in the long run. Thus, the model can represent the process of market penetration of new or modified technologies and analyze their effects on energy conservation. These policy and program variables are addressed in more detail in Section C below.

C. Current Policy Analysis Capabilities

1. Building Energy Performance Standards and Appliance Efficiency Standards

The Oak Ridge National Laboratory (ORNL) Commercial Energy Model computes the impact of building energy performance standards on energy use for:

(a) Space heating

(b) Space cooling

(c) Water heating

(d) Lighting.

The standards are modeled as minimum fraction efficiency improvements for new buildings. The model accepts, by building type, by fuel, and by end use, the ratio of energy use per square foot for new buildings built under the standards to the average energy use per square foot in the initial year. The energy use per square foot in new buildings is the minimum chosen from the imposed standards ratio and from that ratio which would voluntarily be selected as energy prices rise, times the initial energy use per square foot.

The model analysis for these is indirect in the sense that buildings thermal performance is integrated into the appliance efficiency in the buildings. It is these efficiencies that are actually used in the model calculations. Investments to increase the thermal performance are translated via engineering process models into percentage equipment efficiency changes in the four major end-use areas. The models assume that these changes in efficiency can take place only in new buildings (addition to the stock or replacement).

The added cost for the commercial sector to invest in upgrading their new building's thermal performance can be calculated by using the model's capital cost building energy use curves to determine the capital cost corresponding to the imposed efficiency or energy use levels (see Figure III-2). This and the resulting savings in fuels use can be used for cost-benefit comparisons of the mandated standards. It is possible with the model structure, however, that the commercial sector will have already responded to rising energy prices and, independent of or in addition to the standards, will have chosen equipment whose efficiencies are below those indicated by the mandated increases in thermal performance.

Because the model assumes that commercial-sector managers make their energy use decisions based on the price of the energy-using service provided (e.g. heat, lighting), the mandated efficiency reductions will also have a counteracting impact on increasing energy use. Higher efficiencies reduce the net cost of the energy services, so that utilization of the relevant end-use appliance could be increased. This type of response is embedded in the utilization function $U_{ij}(P_T)$.

2. Appliance Efficiency Standards

These may be modeled using the same procedures used to model building energy performance standards above. Appliance efficiency levels are constrained to be above the standard minimum for all new and replacement appliances. Originally, the model presented the standards as affecting appliance choice only in new buildings, but more recent versions also permit efficiency changes in replacement equipment.

3. Building Retrofit - Schools and Hospitals Grants Program

The ORNL Commercial Model computes the impacts of the federal program to grant funds to schools and hospitals for energy conservation investments. The model accepts several inputs to define the grants program:

(a) Beginning year of grants program

(b) Ending year of grants program

(c) Grants per square foot for schools

(d) Grants per square foot for hospitals

(e) Grants program years divided by fraction of square feet affected.

The evaluation is based primarily on the engineering-determined capital costs-versus-structure-efficiency curves such as those indicated earlier in Figure III-2. At a given grant level (for example a grant to invest in heating and cooling equipment), the model uses these curves to identify the improvements in efficiency that can be achieved. From this efficiency choice, and the floor space relevant to the equipment, fuel savings with respect to the baseline case can be calculated.

4. Investment Tax Credit

The ORNL Commercial Energy Model computes the impact of an investment tax credit on energy consumption by reducing by the percentage of the tax credit, the capital cost of energy conservation investments; for example, a 10 percent credit would lead to 10 percent lower capital costs. As the capital costs are reduced for a given level of fuel prices and technologies and an estimated discount rate, the model technology descriptions (Figure III-2) indicate increased investment in efficient equipment. The capital cost efficiency curve rotates to the left -- lower costs for the same efficiency. Lower capital cost permits a new minimum life-cycle cost and enables present equipment expenditures to reduce future operating costs.

In addition, the assumptions can be made that energy conservation investments planned by the firm for after the tax credit period will be expedited to take advantage of the investment tax credit; investments that would have been made several years after the tax credit program ends could instead be made during the last year of the program.

The ORNL Commercial Energy Model accepts three inputs to define the investment tax credit program:

(a) Year in which investment tax credit takes effect

(b) Last year of investment tax credit

(c) Fractional amount of tax credit.

Analyses of the impact of the credit require comparisons of the energy use and fuels consumption projected without the credit to those with provision of the credit. Fuel savings from this would then be compared for cost-benefit purposes to the model forecast of the incremental investment cost induced by the credits.

5. Conservation Technology Research and Development

The ORNL Commercial Energy Model can simulate the impact of research and development on building energy use by modifying the capital cost of conservation investments and by reducing the efficiency limits. The model accepts a maximum allowable efficiency improvement, that is, the minimum ratio of energy use per square foot in new buildings to energy use per square foot in existing buildings. As technological improvements reduce this minimum ratio or reduce the cost of conservation investments, the model will show new buildings with greater potential for more efficient equipment, thus reducing overall energy use.

In effect, the research and development for more energy-efficient equipment or structures shifts the capital cost-efficiency curves by reducing the capital costs for the same efficiency; and extending or reshaping the curve to portray new efficiency levels.

6. Low-Interest Loans

The ORNL Commercial Energy Model can analyze the effect of low-interest loan programs in two ways. First, loans could be translated into an effectively lowered capital cost for energy-conserving equipment. Such a lowered cost, as discussed in previous sections, would shift the capital cost efficiency engineering curves so that a new level of more energy-efficient equipment would be undertaken for new buildings and to replace retired equipment.

Alternatively, the impacts of low-interest loans might be simulated by reducing the discount rate used in making energy conservation equipment decisions for commercial buildings. The lower effective interest rate could be seen as lowering the discount by attacking imperfections in the capital market that inhibit commercial-sector investors from making cost-effective decisions. A lower discount rate translates into enhanced evaluation of future energy cost savings for the same capital expenditure and efficiency level. More energy-efficient investments at higher capital cost are thus cost effective according to the model's minimum life-cycle cost evaluation.

7. Fuel Price Modification

The ORNL Commercial Energy Model computes the impact of policies that change the average price of energy, by fuel type. These were discussed earlier in B.7. Changing energy prices have three effects on the model:

- Changing the fuel market shares for new construction
- Changing the efficiency of new building and equipment
- Changing the energy use in all buildings to reflect revisions in building operational practices.

The share of new construction using electricity, natural gas, fuel oil, and other fuels (propane) for space heating is an input function of the relative fuel prices. As the price of one fuel increases relative to other fuel prices, the share of new construction using the more expensive fuel for space heating declines.

The ORNL Commercial Energy Model determines the efficiency of energy utilization in new buildings by discounting the fuel savings from energy conservation investments at an input discount rate and comparing the resulting present value of fuel savings to the conservation investment cost. As fuel prices increase, future operating costs decline, future fuel savings increase, and more investment in conservation becomes cost-effective.

The ORNL Commercial Energy Model accepts operational elasticities of equipment utilization. These elasticities are the percentage change in energy use divided by the percentage change in energy cost, expressed as an absolute value (without sign). For example, if the elasticity of equipment utilization with respect to energy cost is 0.3 and energy costs rise 10 percent, then energy use would be reduced by 3 percent ($1.1^{-.3}$). Thus as energy prices rise, energy use per square foot will be reduced as higher energy costs lead to reduced operation of energy-using equipment.

D. Extending the ORNL Commercial Energy Model for Energy Conservation Analysis

Current versions of the ORNL Commercial Energy Model, although applicable to a broad range of energy conservation programs, could be enhanced by reducing several limitations on the types and/or precision of analysis of conservation programs that can be simulated. The following discussion will consider both extensions of the model to better address key conservation issues or variables, and refinement of the inputs, coefficients, and model algorithms that could improve the basic forecasts. These are presented in the context of possible ways of modifying the model or incorporating changes into the model structure.

The topics were selected, after discussion with DOE, on the basis of the value of the model changes to DOE commercial energy conservation program objectives. (See the Appendix to this report for a discussion of these objectives.) The topics are not intended to represent all major areas where the model could be enhanced. They are, however, priority areas of significance for application of the model for future commercial energy conservation planning and policy analysis.

Topics addressed include:

1. Retrofit of existing commercial buildings and their appliances for higher thermal performance and energy efficiency
2. Operational conservation measures
3. Rate structure and load management
4. Alternative energy supplies - solar space and water heating
5. Alternative energy supplies - district heating
6. Energy conservation in federal buildings
7. Energy conservation in state/local buildings
8. Building ownership and energy conservation - analysis of renter/landlord effects
9. Utility activities
10. Regional energy use and conservation activities
11. Technical improvements in the base case of the ORNL Commercial Energy Model
    a. Technology characterization of building energy performance and equipment efficiency
    b. Energy use per square foot

c. Commercial-sector behavior and investment decisions

d. Floor-space additions

e. Building categories

f. Equipment decay rates

g. Oil and gas predictions.

In reviewing these topics it should be recognized that the ORNL Commercial Model is installed and/or used for analysis with a large number of organizations. There also exist a number of versions and special applications of the model by DOE and ORNL as well as ongoing model development at these institutions. It is entirely possible that several of the changes or extensions suggested in the following discussion have already taken form elsewhere. An informal survey of the forthcoming versions and of work in progress is presently underway by the authors of this report. For the discussions below, the analysis has focused on the national versions originally described in The Commercial Demand for Energy: A Disaggregated Approach (Jackson, et al., April 1978) and updated in Energy Use and Conservation in the Commercial Sector: An Econometric-Engineering Analysis (Jackson, January 1979); and in the regional version described in Commercial Energy Use Model for the Ten U.S. Federal Regions [Cohn, et al., April 1979 (Draft)]. These are, for the most part, production versions in use at EIA and ORNL. Changes in these are most likely to affect DOE conservation policy development and program planning and evaluation.

1. Retrofit of Existing Commercial Buildings and Their Equipment for Higher Thermal Performance and Energy Efficiency.

The ORNL Commercial Energy Model currently only computes the impact of a federally funded retrofit program for schools and hospitals. (See the discussion in C.3 above.) For these, the model accepts the expenditures per square foot for retrofit and duration of the retrofit program. The model then computes the energy conservation investments using an input technology characterization function (e.g. Figure III-2) to relate expenditures to equipment choice. The model simulation then permits analysis of the final energy savings by comparison with the non-retrofit case.

Higher energy prices and conservation programs, such as tax credits for retrofit conservation investments, should encourage retrofit in all existing buildings. To model the impact of these incentive programs within the current model structure, a relatively simple procedure would be to program the code so that it permits the numbers of retrofit buildings and their increases in efficiency (end-use performance) to be input for each building type by end use and fuel type. The calculation of the numbers and efficiency gains would have to be calculated outside the model, with care given to the vintage (age) of the building for any retrofit of buildings built after 1970. (In the model, each building type built before 1970 has only average efficiency and fuel usage factors for the entire pre-1970 period.)

Alternatively, a more significant modification would permit the model to endogenously represent the retrofit behavior. First, the model could be modified to accept as input the initial fraction of existing buildings which might benefit from retrofit. Various commercial building data bases could be examined to determine those fractions, by building type. Second, the model would need to be modified to compute the change in efficiency from retrofit, using the technology characterization functions (capital cost efficiency trade-off) adjusted to reflect the incentive programs. Third, the model would determine the fraction of the stock remaining to be retrofit each year, simulating the declining program impacts as old buildings or potential equipment for retrofit are removed and the existing stock becomes more efficient. A minimum life-cycle cost level of retrofit would indicate the investment levels for the identified fractions. To test a retrofit incentive program impact, the model would be run twice: first, with a technology characterization function lacking incentives; and second, with the function modified to reflect reduced cost of retrofit as a result of the incentive programs.

The accounting and data problems of identifying retrofittable equipment within existing buildings is significant even with the existing appliance decay function. The existing decay structure has replacement at the same time for all equipment of a given age in a building of a given age. A more realistic distributed decay would have buildings of the same age with a variety of equipment vintages. (See D.11.f. below for further discussion of equipment decay rates.)

Despite the difficulties of modification, if it is accepted that rising energy prices, improved technology, and federal incentive should affect appliance retirement or "trade-in" decisions, then the retrofit modification could provide significant results. Otherwise, the effects of the conservation incentive are severely constrained to affecting only the relatively small annual numbers of additions and replacements of the (much larger) total stock of commercial buildings and their energy-using equipment.

2. Operational Conservation Measures

The ORNL Commercial Energy Model currently simulates the influence of higher energy costs on the operation of equipment, using input elasticities. The model does not provide for direct simulation of the impact of operational conservation measures such as thermostat setback, reduced hours of operation, or of delamping. For conservation investments in new buildings and equipment, some of these operational measures appear to be incorporated within the capital-cost-versus-efficiency technology curves developed for later versions of the model. For these, commercial enterprises may choose the operational measure to be cost effective in the minimum life-cycle cost sense, depending on fuel price levels and conservation incentives. If the model does include operational changes in the technology curves, then the effect of operational regulations could be simulated for new buildings in a manner very similar to that of building and appliance energy efficiency standards discussed in C.1. The operational standard would shift the technology curve and the commercial sector would choose new equipment which equaled or exceeded the operational requirement.

The basic operational conservation responses, however, are potential and in fact ongoing to some extent for all buildings and equipment, not only new additions and replacements. To be able to account for these in the model, the short-run operational elasticity equation for any building and end use would need to be modified to accept the constraint of a maximum operational level. This operational level would be calculated outside the model as the relative reduction in Btu per square foot for a given building type, if a specific operation were undertaken (e.g., Btu/square foot reduction effect of a 5 degree lowering of the thermostat on weekends). Specified energy-using facilities in a given type of commercial building would then be modeled to operate at or below the mandated level. The short-run utilization elasticity would still be operative below the specified level.

3. Rate Structure and Load Management

The ORNL Commercial Energy Model accepts input forecasts of average annual energy prices, by fuel type, and computes commercial energy demand on an annual basis. The same fuel price is applied to each end use. Because of this, the model cannot be used to evaluate the impacts of rate structure options, which include:

(a) Conventional declining block rates in which unit cost decreases with quantity consumed

(b) Level rates in which unit costs are constant

(c) Inverted or lifeline rates in which unit costs increase with quantity consumed

(d) Incentive rates in which usage in excess of a percentage of the prior year's usage (e.g., over 90 percent of prior-year use) is priced above the base price.

Similarly, because the model only calculates annual energy use and does not calculate the hourly load profiles of electrical equipment usage, the model cannot assist the planner in evaluating load management programs. Load management programs include:

(a) Direct load control in which the utility can cycle customer equipment (e.g., air conditioners)

(b) Timers that limit the time of operation of appliances (e.g., water heaters)

(c) Storage devices that store energy at night (or over seasons) for use during peak periods of electricity use

(d) Time-of-use electricity rates.

However, more permanent national or regional rate changes could be approximated by appliance-specific reestimation with those rates and inputting appropriately "averaged" rates for these using estimations from outside the model. This still corrects only the initial demand/price position, but there is generally no time series data available for full responses of commercial enterprises by building structure or end use to changes in rate structure. Thus even if the model were newly estimated to the national or regional average rates, the model would not reflect changes in the distribution of rates within that new average. Continued reestimation with each change in rate structure or provisions for exogenous inputs from engineering energy load models appears impractical, as a general procedure.

Alternatively, the model might be entirely restructured for a utility service area over a shorter time period (e.g., seasonally or daily), and then applied with a submodel of engineering-determined load curves analyzed for building or commercial enterprise types.* In this analysis, building

**Efforts to investigate this are being considered by Dr. Jackson at the Georgia Engineering Experiment Station. Conversation with Dr. Jackson, July 8, 1980.*

types would need to be further disaggregated to a level of detail that would permit better classification of their total use and their responses (for example, rates that depend on quantity consumed may differ simply because the building size creates differences in billing rates). Commercial establishment response to the rate will also depend heavily on the type of commercial activity (for instance, restaurants may be less able to respond to hourly rate than laundries). The present building classifications do not adequately represent commercial enterprise categories (i.e., specific SIC industries). Since several commercial industries may also be in the same building, detailing a specific response would require disaggregating the building types.*

4. Alternative Energy Supplies - Solar Space and Water Heating

The ORNL Commercial Energy Model accepts as input a technology characterization function that relates installed space heating capital cost to annual energy use (efficiency). Figure III-2 presents an example of this technology characterization function. As described earlier, life-cycle cost minimization using this efficiency-versus-capital-cost trade-off indicates the direction for new commercial-sector purchases of housing energy conservation installations and of appliance investments (see Section B.3). Energy use per square foot of floor space per annum may be reduced by installation of more efficient systems, with an associated increase in installed costs.

With appropriate data, the technology characterization functions could be modified to reflect solar space heating options, leading to further reductions in energy use at greater installed costs. However, the resulting model output would only indicate the utilization of the backup fuel and would not reveal the solar contribution.

Solar space and water heating could be explicitly treated by modifying the ORNL model. The structure of this modification is displayed in Figure III-3. The first step, embodied in the existing model, is the choice of a fuel for space heating; comparable logic would be added for water heating. The second step would be the choice between conventional fuel-using systems or solar with electric backup. The third step would be selection of the efficiency for the conventional system and the efficiency as well as solar contribution for the solar system, by fuel type. This structural modification

**BDM, Inc., is presently undertaking a study for EIA investigating the commercial classification formats for commercial-sector energy conservation analysis. The draft report should be released in August 1980.*

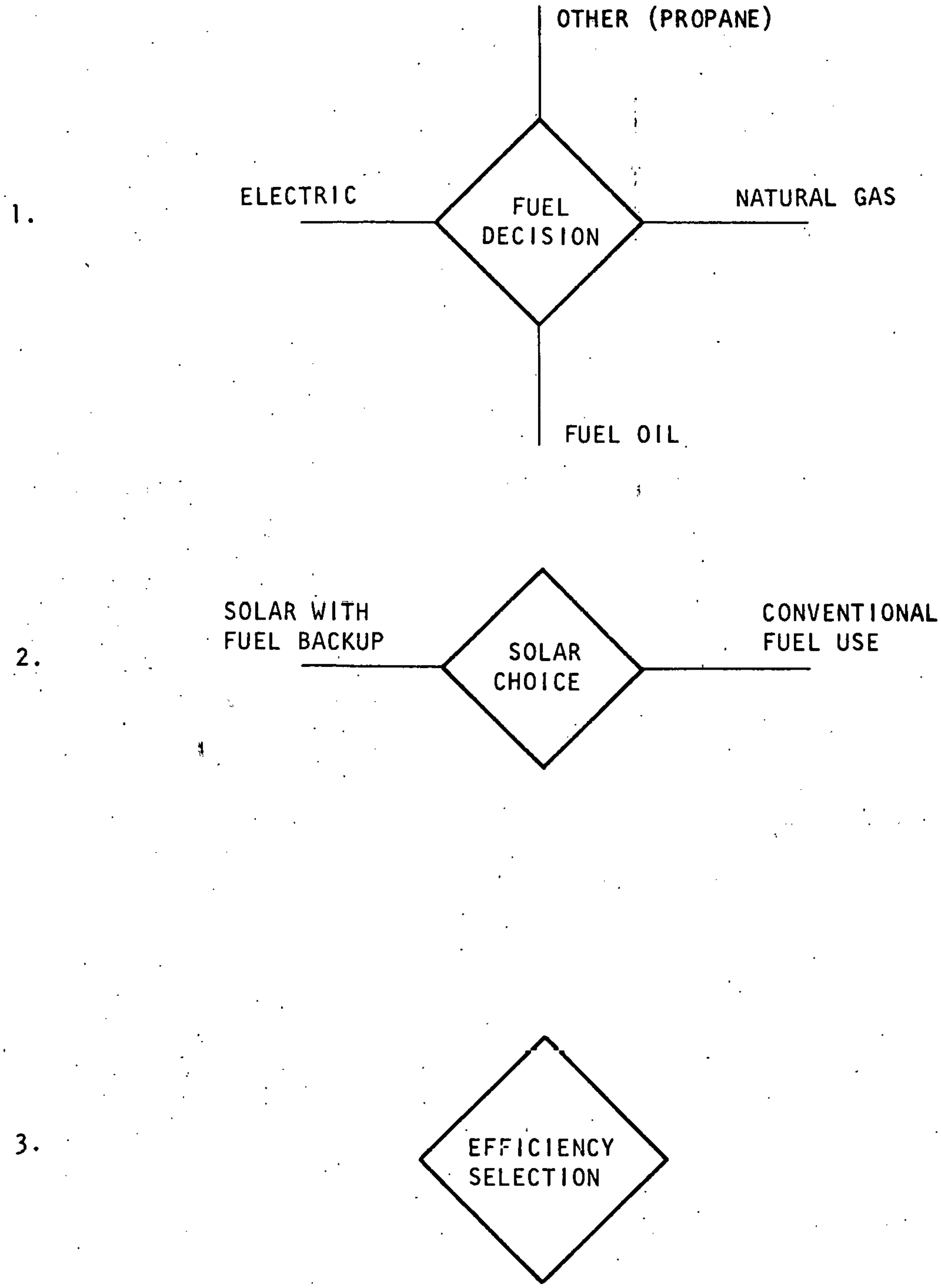


Figure III-3. Structure of ORNL Commercial Energy Model Modifications to Explicitly Treat Solar Space and Water Heating involves adding the second step, the solar/conventional choice, to the model and providing a technology characterization function (e.g., Figure III-2) for solar with fuel backup.

These modifications would have several benefits:

(a) Embodying solar options within the same model used for conservation policy analysis and mid-range forecasting

(b) Providing a capability to simulate the impacts of policies to increase the market penetration of solar

(c) Providing the capability to simulate the impacts of policies which favor both conservation and solar energy.

Data for the technology curves, life-cycle cost analysis and consumer demand appear to be available from solar space and hot water modeling analyses sponsored by DOE and integrated into solar market development and commercialization models. Such models include the DOE/Arthur D. Little Solar Market Development Model, the DOE/Orkand Corporation Simulation of Solar System Performance and Market Penetration Model (SOLARSIM), and the DOE/MITRE Corporation System for Projecting the Utilization of Renewable Resources (SPURR).* A major effort, however, would be necessary to value the data fully commensurable with ORNL commercial sector definitions and the parameter estimates from different sources.

5. <u>Alternative Energy Supplies - District Heating</u>

The ORNL Commercial Energy Model calculates consumption of electricity, natural gas, fuel oil, and other (primarily coal and propane). It does not currently simulate use of steam for district heating. Similarly, it does not evaluate the market penetration of windmills, photovoltaic, and total energy systems in the commercial sector.

District heating systems provide steam, generally for space heating of large apartments and commercial buildings. This is available in 43 cities in the United States. District heating is apparently included within the other fuel

**Sources given in the Bibliography. See also Section K of Hittman Associates, Inc., <u>Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis</u>.*

use category in the current model, but the other fuel price is the price of propane and coal, which are quite expensive relative to district heat where it is available.*

Several steps would be required to explicitly treat district space heating within the ORNL Commercial Energy Model. First, the floor-space fuel share equation for space heating would be modified to reflect district heating. The district heating market share would need to apply to space heating in limited geographical areas within the model's coverage; the market share would be multiplied by the fraction of floor space where district heating is available. Market share elasticities including district heating then would be developed. Second, the model would be modified to accept an input price of district heat. Third, technology characterization functions would need to be added for district heating equipment and their efficiency levels. Fourth, the section of the model which prints out forecasts would be modified to display projected district heating.

6. Energy Conservation in Federal Buildings

The federal government is currently under executive order to develop a 10-year program to undertake energy conservation in federal buildings (Executive Order 12003, July 1977). Initial goals of this Federal Energy Management Program (FEMP) are to reduce by 1985 energy use per square foot by 20 percent in existing buildings and 45 percent in new buildings relative to 1975 energy use.

In principle, the ORNL Commercial Model is well suited to cost and the impact of predetermined or target efficiency increases as given in FEMP. Target increases in efficiency can be used to constrain the minimum efficiency for new buildings and (with the retrofit methodology of D.2 above) for existing buildings. In fact the model can be applied only indirectly, due in part to general lack of data on energy use in federal buildings, and in part to the fact that the model structure does not have a separate federal buildings sector.

Conservation input data such as energy use per square foot are not available or not comparable across agencies for either the building types or the agency as a whole. Without building energy audit information, it will also be difficult

**District heating is included in the New York State version but only for accounting purposes. It is not actually integrated into commercial fuel use and investment behavior.*

to determine whether the energy consumption is due to buildings-related use or to other federal space use (e.g., military vehicle storage) operations. DOE is collecting quarterly energy-use data from all agencies and requires building energy audits. When this data collection methodology is worked out, this should provide the needed inputs for model evaluation. In the meantime, application of the ORNL Commercial Energy Model must rely on data from other building types.

In the ORNL model, federal buildings are spread among several ORNL Commercial Model building types. Jack Faucett Associates has made estimates of energy use by regions for federal buildings; these regional estimates reflect data from federal agencies that use most of the energy in buildings.* Office buildings, hospitals, and public buildings appear to be the key federal energy users by ORNL commercial building types. This approximation and estimates of future federal building programs permit partial estimates of FEMP impacts.

The model could be modified to accept input estimates of efficiencies or energy use for new federal building programs for the appropriate ORNL building category. Estimates of the federal fraction of floor space could yield the net savings for FEMP alone. If the model were modified to accept the fraction of existing buildings retrofitted, as discussed in D.2 above, the code could simulate in a similar fashion the savings from programs for weatherization. The cost estimates for the FEMP investments would be calculated from the model's technology capital cost-efficiency curves, again reflecting the role of federal buildings in each building type.

When the energy inventory and audit of federal buildings are satisfactorily completed, a separate federal building category for the model could be created. There will still be some difficulty in adjusting the historical data series on floor space, but the accuracy of projecting FEMP impacts could be considerably enhanced.

Operational changes in federal buildings, such as the elimination or reduction of hot water for office buildings, would require an exogenous estimate of the minimum energy utilization reduction to apply to the model's utilization elasticity equation for each building type and end use. (See Section D.3 above for additional discussion of this.) Again, with present limited data, a percentage saving estimate would

Jack Faucett Associates, Inc. *Energy Consumption in Commercial Industries by Census Division - 1974*, *FEA 1977. See also Hittman Associates, Inc.* *Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis*, *Section D.*

have to reflect the role of federal buildings in each building type considered.

7. Energy Conservation - State/Local/Institutional Buildings

Buildings owned by state and local government or institutions (e.g. nonprofit organizations) are probably placed in several ORNL model building types:

- Office
- School
- Health
- Public administration
- Religious
- Miscellaneous.

Difficulties of model analysis are very similar to those in federal buildings discussed above. The solutions, however, appear to be somewhat simpler.

The model currently can simulate the impacts of a grants program for schools and hospitals. For this, the model accepts the years of the grants program and the expenditures (grant) per square foot for schools and for hospitals (see Section C.3 above). The model then calculates the efficiency increases and simulates the impact of these grants on retrofit thermal integrity.

Rough estimates have been made by Jack Faucett Associates, Inc., of the total national energy use by state and local governments; these estimates have been scaled to Census Regions using state/local government employment as a scaling factor.* State energy conservation plans also reflect government building data and state programs.** Some states require utilities to report energy sales by Standard Industrial Classification (SIC) Code**; SIC code indicates total governmental activities and can be used to estimate state/local

*Jack Faucett Associates, Inc. Energy Consumption in Commercial Industries by Census Division - 1974, Federal Energy Administration, 1977. See also Hittman Associates, Inc. Major Models and Data Sources...Section D. "End Use Consumption Data Base."

**Nevada Public Service Commission. "Nevada Energy Conservation Plan," 1977.

activities. A variety of special state studies, building stock estimates, and commercial building energy surveys, including the Nonresidential Buildings Interim Energy Consumption Survey, provide separate state/local government buildings energy use data.* Thus the data exist to estimate energy use and building stock for state/local and institutional buildings on a national basis and could be compiled on a regional or state basis. However, with the exception of the grants program for weatherization of schools and hospitals and of building energy efficiency standards for new buildings, the ORNL Commercial Energy Model does not currently accept building-type-specific conservation program inputs.

The ORNL Commercial Model could be modified to reflect state/local/institutional programs. A simple modification would be to provide for an input annual fuel savings, by fuel type, for these buildings in the total commercial sector. This conservation program input could reflect state/local/institutional programs or other programs not within the model's current simulation capability. A greater degree of policy simulation capability would be achieved by providing for an input percentage savings, by building type, along with the fraction of each building type affected by the program. The savings input would apply to retrofit programs; programs for new buildings can be incorporated in the building efficiency standards inputs. A review of state/local/institutional fuel use and building stock data would be needed to determine appropriate program inputs for impact estimates.

8. Building Ownership and Energy Conservation -- Analysis of Renter/Landlord Effects

The ORNL Commercial Energy Model excludes residential energy use within commercial buildings and excludes master-metered apartments, which are commercial natural gas or electricity customers.

However, commercial space is master metered quite often: electricity for an individual office suite in an office building is typically reflected in the rent, rather than separately metered for each company occupying the building. Data in Table III-1, from an onsite survey of 500 California commercial buildings, indicate that the extent of master metering varies significantly between building types. Table III-1 also indicates, for example, that the role of buildings owned and occupied by the same firm is quite low for office buildings but high for hospitals.

**See Hittman Associates, Inc. Major Models and Data Sources ...Section I. "Nonresidential Buildings Survey" for a discussion of the forthcoming results.*

TABLE III-1. CALIFORNIA COMMERCIAL BUILDING OWNERSHIP AND METERING (%)

Building Type	Master Metered*	Owner-Occupant**
Low-Rise Office	78	9
Mid-Rise Office	92	18
High-Rise Office	94	6
Small Detached Retail	9	45
Small Attached Retail	0	31
Mid-Size Attached Retail	11	11
High-Rise Department Store	7	93
Refrigerated Warehouse	33	17
Non-refrigerated Warehouse	29	29
Fast Food Restaurant	0	32
Sit-down Restaurant	30	5
Small Food Stores	0	4
Lage Food Stores	7	7
Hotels	44	11
Motels	0	6
Schools	17	80
Hospitals	16	97
Repair Services (automotive)	54	54
Miscellaneous (telecommunications)	0	94
Computer Centers	100	66
Gasoline and Service Stations	0	10

**Electricity bills included in rent/lease payment.*
***Indicated ownership: nonresponse assumed to be renter/leaser.*

Source: Hittman Associates, Inc., Commercial Building Survey for California Energy Commission.

Table III-2 shows that, for the same list of commercial businesses, the prevalence of conservation activities such as metering and ownership also varies significantly between building types.

The ORNL Commercial Energy Model computes the efficiency of new buildings using an input discount factor to determine the minimum life-cycle cost equipment efficiency choice. Operational response to fuel price increases is modeled using an input set of fuel price elasticities. To simulate differences in incentives for equipment selection (differences in role of owner-occupant) and for operational conservation measures (differences in role of master metering), the model could be modified so that the discount factor and fuel price elasticities could differ between building types. Differences between discount rates of the various buildings could reflect differences both in ownership types and the proportion that pay their own electric bills.

Data for this simulation could be derived from data sources such as Tables III-1 and III-2. Also, when available early in 1981, the Nonresidential Buildings Interim Energy Consumption Survey will indicate ownership, master metering, and conservation behavior for all fuels, as well as measures of energy prices and consumption.

9. Utility Activities

Voluntary or prescribed actions for private and public utilities to foster increased commercial energy conservaton are only partially amenable to analysis with the present ORNL Commercial Model structure. Several applications and extensions of the model to incorporate these are given below. This discussion incorporates portions of the analytical discussions and several changes introduced in earlier sections of this chapter.

a. Energy Audits. Energy audits permit building owners to be aware of retrofit conservation opportunities. However, with the exception of school and hospital grant pograms, the ORNL Commercial Energy Model does not presently simulate retrofit programs. To estimate the impacts of retrofit weatherization programs, the model could be modified to accept separate initial cost/annual energy use data for retrofit of existing buildings and to accept an input fraction of buildings retrofit. The model would determine the savings from retrofit based on minimum life-cycle costs.

However, as would be necessary for analysis of most utility programs, energy audit impact estimates on a regional or national basis would require gathering data on the status

TABLE III-2. ELECTRICITY CONSERVATION PROGRAMS BY BUILDING TYPE IN CALIFORNIA (%)

Building Type	Manage kW Load	Manage kWh Demand	Manage kW + kWh	Manage Lighting Only	Manage Lighting and kW	None
Low-Rise Office	4	0	23	19	2	52
Mid-Rise Office	0	0	43	29	0	29
High-Rise Office	0	0	74	6	0	20
Small Detached Retail	0	8	0	33	0	58
Small Attached Retail	0	5	0	53	0	42
Mid-Size Detached Retail	0	0	0	35	5	60
High-Rise Department Store	7	0	0	0	13	80
Refrigerated Warehouse	0	0	0	29	0	71
Nonrefrigerated Warehouse	0	0	0	57	0	43
Fast Food Restaurants	0	0	0	5	0	95
Sit Down Restaurants	4	0	16	16	0	64
Small Food Stores	0	0	0	66	0	34
Large Food Stores	0	3	7	31	0	59
Hotels	9	9	18	0	0	64
Motels	0	7	0	20	0	73
Elementary/High School	9	2	3	16	0	70
College	33	0	17	33	0	17
Hospitals	3	3	42	48	0	4
Repair Services	17	0	17	0	0	66
Miscellaneous	11	2	11	7	2	67
TOTAL	4	2	18	23	1	52

Source: Hittman Associates, Inc., Commercial Buildings Survey for California Energy Commission.

of utility programs within the region. Regional impact estimates would reflect both the effectiveness of programs and the role and ratio of the participating utilities in regional commercial energy sales.

b. Standards for New Utility Customers. Buildings standards required for new utility customers in some utility service areas can be simulated in a manner similar to the way the model currently simulates the effect of building efficiency standards (see C.1. above). Changes would be necessary, however, to incorporate in the regional or national simulation the role of the standard-setting utility in regional commercial energy sales.

c. Changes in Rate Structure. The ORNL Commercial Energy Model uses average energy prices to model the choice of fuel for new buildings and the operational response to price changes. Some utilities are changing from declining block rate structures to level and to seasonal rates, implicitly changing the price of energy for space conditioning use. To model these changes, the ORNL Commercial Model could be adapted to accept different energy prices for space conditioning and nonconditioning uses.

d. District Heating. District steam heating of commercial buildings occurs in geographically concentrated zones within about 44 utility service areas.* The ORNL Commercial Model includes an "Other" fuel category, but the economics generally reflect those of using propane, rather than district steam. Since district steam is regionally limited in availability, modeling district steam market penetration could be accomplished by specifying a different fuel type (steam) and an input market share, reflecting geographical limitations. For service areas with steam available, market penetration could be modeled using techniques analogous to those for other fuels in the current model. That is, market share elasticities would need to be developed consistent with the existing elasticities, the model modified to accept the input price of district heat, and the technology characterization factors added for capital cost efficiency trade-offs.

e. Prohibition on New Electricity Uses. Prohibitions on new electricity uses, including electric resistance space and water heating, cannot be simulated in the current ORNL Commercial Energy Model. These programs could be modeled by permitting the user to prohibit a fuel type for new buildings, forcing the market share to be zero for new buildings using resistance heating. Alternatively, the initial cost/annual

**International District Heating Association, 1976 Statistical Survey.*

energy use trade-off data could be modified to remove the resistance option for new buildings.

f. Load Management and Electric Rate Changes. The ORNL Commercial Energy Model projects annual electricity use. Utilities are participating in programs to reduce peak period electric demand through load management (direct/remote control of building equipment) and time-of-use rates. To simulate these programs, a considerable model extension would be required:

(1) Developing typical load profiles by building type and end use

(2) Developing an algorithm to modify the profiles reflecting load management and time-of-use pricing policies

(3) Developing a model to project commercial-sector energy demand with respect to these varying rates.

It is possible to modify the ORNL model at the utility service level to accept the sum of a fixed change in time of use and load management as a net change in the utilization factor over the model's new time period (day or week). This will not, however, account for future changes in rate structure or new load management efforts.

g. Voltage Reductions. The ORNL model could be modified to simulate the impacts of utility voltage reductions to commercial customers by inputting the percentage reduction in electricity use as a maximum constraint to the utilization factor for each affected end use. The modification would be similar to those suggested in Section D.2 for model changes in operational factors.

10. Regional Energy Use and Conservation Activities

The ORNL Commercial Energy Model has been disaggregated by federal region, states, and three regions within New York State. The version for the 10 federal regions is available at EIA as the commercial model of EIA's Regional Energy Demand Forecasting Model (RDFOR) and as EIA's stand-alone version, the Structural Commercial Energy Model. The state-level version has been developed very recently for EIA by Charles River Associates. Runs of this state model are available but the structure of the model itself has not been documented. The New York State model was developed for the New York State Energy Office, dividing the state into three regions. An additional state version is under development by the California Energy Commission.

Detailed documentation for the regional model is available primarily for the federal region model: A Commercial Energy Use Model for the Ten U.S. Federal Regions (Draft) (Cohn et al., April 1979). This is the primary basis for the discussion that follows.

Each separate region of the federal region version, as well as the state-level version, relies primarily on the national model structure as described in Section B of this chapter. The federal region model does have distinct regionally estimated inputs for:

(a) Initial energy use per square foot by building fuel and end use

(b) Initial floor-space fraction by fuel type and end use

(c) Floor-space stock from historical regional construction

(d) Addition to floor space per building as a proxy for capitial stock

(e) Elasticity parameters for fuel shares of floor space.

Several major improvements would be useful to better differentiate regional responses and impacts. These are discussed below.

a. Technology Coefficients. Estimates of equipment capital cost versus energy use (efficiency) curves for heating, ventilating, and air conditioning equipment (HVAC) are the same for all regions and the same as used in the national model. For the national model, differences in climatic conditions for the technology representation of HVAC equipment were excluded since national variations in average heating degree days and cooling degree days were relatively small. Variations across regions and within individual regions, however, can be considerable. For example, heating degree days vary from a low of 2611 in the lower Western states to a high of 7792 in the upper Western mountain states.*

*From Cohn, et al., A Commercial Energy Use Model for the Ten U.S. Federal Regions, ORNL/CON-40. April 1979, pp. 7 and 8.

The relative efficiency of the equipment and, therefore, choice of equipment should vary with the average temperature. Relatively less-efficient equipment and building thermal performance would be expected in warmer regions. Increases in fuel prices in these regions would generally be expected to bring about larger efficiency changes and greater investment costs than in the cooler regions. Therefore, in the existing regional models, penetration of more efficient technologies would be biased downward for warmer areas.

Data for estimating these separate regional capital-cost-versus-thermal-performance curves for buildings appear to be available from the ongoing buildings energy use estimates. An example is the DOE-2 model commercial building runs for the Buildings Energy Performance Standards (BEPS) analysis. Similarly, appliance data for the regional capital-cost-versus-appliance-efficiency curves should be available from the appliance efficiency standards analysis at DOE (see, for example, Technical Support Document No. 5, Energy Efficiency Standards for Consumer Products, DOE/CS/BCS, May 1980), as developed from appliance analysis at Arthur D. Little, Inc.

b. Market Share and Utilization Elasticity Estimates. The federal region version of the Commercial Energy Model employs national elasticity estimates of overall fuel usage and of overall fuel market shares where coefficients are estimated from 1968 to 1972 state-level data on fuel use, fuel prices, climatic variables, per capita income, and the availability of natural gas.* There are insufficient degrees of freedom in the data to estimate state-level coefficients, and only the national coefficients are available. As described in Section B of this chapter, these coefficients are used to calculate the short-run utilization elasticity, the long-run efficiency elasticity for non-HVAC equipment, and the long-run fuel choice elasticities in the regional models. The fuel shares and utilization will vary by region since floor space, per capita income, and climatic conditions are variable in the equations. However, the actual behavior is still based on the nationally averaged coefficients, and relative behavior (elasticities) toward fuel price changes is the same for each region.

Estimates to partially rectify this problem for the same state-level data source might be available using regional level slope and intercept variables to adjust these elasticity and intercept estimates in the fuel usage equation. Whether these estimates would be statistically significant requires further analysis since, with only four years in the pooled

**See Cohn et al., op cit.*

state-level cross-sectional data, estimation techniques are limited and certain biases in the estimated coefficients might occur.

c. State-Level Analysis. The 10 DOE region version of the ORNL model is an ongoing, regularly updated entity used for analysis at EIA (as the Structural Commercial Energy Use Model) and as part of the DOE Midterm Energy Forecasting System (MEFS); this is additionally running at a number of other institutions as well as at ORNL. However, similar application of the state-level model has not occurred at DOE since state-level data forecasts and inputs have not been high priority.

The state-level model is available through DOE-sponsored development by Charles River Associates. Although documentation is not yet available, the state-level disaggregation and estimates of inputs and coefficients presumably parallel the regional version. State-level data are already employed for the regional version estimates of floor space, fuels, and energy use.

The state-level analysis of commercial energy demand can be of considerable importance to energy conservation policy and planning. Recent application of the model to New York State and in California indicates that some states do value the potential that this model offers for their state-specific conservation planning. To enhance this interest and strengthen the modeling effort, more interest in state-level forecasts would need to be forthcoming from DOE. Efforts would have to be made at EIA to collect and project state-level input data for the simulations. Reestimation of the elasticities and the technology characterization at the state level could follow after initial interest and evaluation.

11. Technical Improvements in the Structure of the Base Case of the ORNL Model

The specification of the base case of the ORNL model could be improved by refining the input data and by improving the model's algorithms and coefficient estimations. A recent review of the model found

> "The disaggregated [ORNL Commercial Model] structure is currently better than the data and econometric results used to quantify the model. ... The paucity of necessary demand data ... and other data inadequacies have forced the model to rely at

times on ad hoc estimates and specifications; though these have generally indicated the direction for necessary data development."*

Suggestions for several of these areas are given in the following:

a. Technology Characterization of Building Performance and Equipment Efficiency. The model is designed to accept technology characterization functions which relate initial system costs to annual energy use. These can be used in a minimum life-cycle cost framework to select system efficiency improvements and capital cost for new buildings and equipment. In the earlier versions of the model in fact, (Jackson 1972, CON-15) no such characterizations were included. The current EIA version includes technology characterization functions for each fuel type for HVAC systems. The most recent improvements in the model appear to include technology characterizations for each fuel and for three separate end uses -- space heating, space cooling, and ventilation.

For the EIA version, differentiation of the capital cost vs. efficiency trade-off curves by building type is not developed by explicit engineering measurements. These are differentiated only by conservation improvement costs per square foot. The latest model version does distinguish separate characterizations for the four major energy-using building types -- retail, office, health care, and educational.

In each version, efficiency changes in end uses other than HVAC can only be calculated from usage elasticity estimates using the long-run overall response to fuel price changes and their netting out the short-run price response and fuel switching. There is some question whether such an efficiency elasticity based on responses to historical prices is applicable to future technology decisions.

It should be noted that the ORNL treatment of technology combines the building thermal performance and the end-use efficiencies into one cost-versus-efficiency trade-off. These e_{ij}'s are building and equipment efficiencies. Improvements in the technology curves include the building improvements as well as equipment purchases.

Improved and expanded estimates of technology characterization functions can be estimated from existing methodologies and data. Johnson and Pierce, 1980, modeled and analyzed commercial buildings using the NASA Energy-Cost

Hartman, R. "Frontiers of Energy Demand Modeling." In: Annual Review of Energy, Annual Review, Inc., 1979, p. 455.

Analysis Program (NECAP). These were used to develop the most recent ORNL functions. Models such as DOE-2 could also provide analysis of energy saving and capital costs for building, fuel, and end-use-specific conservation changes. In the future, it might be possible to integrate a simplified engineering buildings energy analysis model directly into the ORNL structure to provide more detailed and accurate efficiency versus capital cost analysis.

b. <u>Energy Use per Square Foot</u>. The ORNL Commercial Energy Model data base includes initial year energy use per square foot by end use, by fuel type, and by building type. These data were developed based on a Hittman Associates, Inc., survey for the Baltimore area.*

There are now more recent, detailed building survey data from other Hittman studies of California cities and several Midwestern states and additional statistics from studies performed by other groups. These data could be used to develop more acurate estimates of energy use per square foot. As ORNL did, the revised estimates could be checked for consistency with total commercial end-use and initial market shares, by fuel type. The Non-residential Building Energy Consumption Survey would also provide data to verify these estimates.

c. <u>Commercial Sector Behavior and Fuel and Investment Decisions</u>. The current versions of the ORNL Commercial Energy Model portray investment decisions for new "systems" (energy-efficient equipment, fuels, and building thermal shells) in the form of two elasticities -- a fuel market share elasticity from econometric estimates, and an efficiency elasticity from technology characterizations, minimum life-cycle cost behavior, and market penetration functions. Ideally, these two decision functions should be combined.

(1) The model's market shares analysis for each fuel currently depends on relative fuel prices. The commercial-sector investor, however, should make fuel choices depend also on comparison of alternative fuels and equipment costs and his discount rate for future versus present energy savings. A minimum life-cycle cost framework is implicit in this.

*Hittman Associates, Inc. <u>*Physical Characteristics, Energy Consumption and Related Institutional Factors in the Commercial Sector*</u>*, HIT-630.*

(2) The model's equipment efficiency estimates portray equipment and conservation technology investment decisions based on minimum life-cycle cost from future operating costs versus equipment price trade-offs. The model must assume some implicit discount rate used by the commercial sector to assess the present value of future energy savings. Estimates of this discount rate are probably best observed through econometric estimates of the parameters affecting capital cost versus fuel price and operation costs decisions.

Estimates of a combined fuel-equipment decision would probably involve a discrete choice model which would estimate the probability that any particular system would be chosen.* Data from a detailed survey of investment decisions could permit such estimates. These would include fuel prices, discount rates revealed in investment decisions, and equipment and building technology characterizations for the given location. Such data do not currently exist, but innovative approaches to data development indicate that perhaps "synthetic" data could be created using the minimum life-cycle cost algorithm and the statistical distribution of input variables for that algorithm.

In the meantime, both the fuel market shares analysis and the equipment efficiency choice analysis in the model can be upgraded. In the fuel choice analysis, the proper fuel price variables should include some measure of price expectations. Also, inclusion of the relative equipment prices of alternative-fuel equipment and measures of relative fuel availability should enhance the estimates. For equipment efficiency choices, additional empirical studies on discount rates would at least permit differentiation of this rate among building types and owners.

d. Floor-Space Additions. Floor space is used in the model as a highly reliable proxy for energy-using capital stock in commercial buildings. Until very recently, floor-space additions in the ORNL Commercial Energy Model were estimated for each building type as a fraction of population, per capita income, and per capita income squared. This equation, and particularly the per capita income squared term, tended to give very large floor-space projections for

Based on discussion on rates with Dr. Jackson, July 8, 1980, on current research prospects at Georgia Engineering Experiment Station.

high-income growth scenarios. Also, estimates of the coefficient of the model were difficult to replicate at the state level.*

Fortunately, ORNL has developed new estimates in CON-40 (Cohn et al., 1979) using log linear relationships between floor space, population, and per capita income. This lowers the year 2000 forecast of floor space by 30 percent in comparison to the earlier procedure. It is important that this update be included in the model versions which are used for commercial-sector energy conservation program and policy analysis.

There are, however, additional functional forms and explanatory variables which could be used to estimate floor-space additions. Studies for the California Energy Commission (CEC) found that the best floor-space forecast results were estimated by using a stock adjustment model. This relationship, though not fully tested by CEC, effectively measured building construction rather than stocks. Exploratory variables used by CEC included an index of building construction costs, interest rates, real personal income, and school age population. Building-specific variables such as automobile projection for garages or patient bed requirements for hospitals could also be important for better forecasts.

Since long-run projections for total energy use from the model are quite sensitive to the floor-space forecasts, additional research for the ORNL model in this area could be important. Conservation policy analyses where floor space does not vary, are, of course, less sensitive to the levels of floor space projected.

e. Building Categories. The ORNL national and regional versions address energy use in only 10 building types. These appear to be highly aggregated where, for instance, the retail-wholesale category combines grocery stores, restaurants, department stores, and liquor stores. While many individual commercial categories are not large energy consumers as a proportion of total commercial buildings energy use, they can have significantly different energy use characteristics.** Additionally, new building types such as computer data centers may have high energy use and rapid rates of market

**Lann, Bob, Conversations with R. Fullen, HAI, April 13, 1978.*

***See, for example, Hittman Associates, Inc., "Physical Characteristics, Energy Consumption, and Related Institutional Factors in the Commercial Sector" for differences in energy use among building types.*

penetration. Energy use estimates to disaggregate many of these ORNL building categories are available from building surveys such as that for Baltimore by Hittman Associates, and data from Jack Faucett Associates.*

f. Equipment Decay Rates. The distribution of equipment lifetimes or conversely the equipment decay or retirement rates play an important role in the ORNL Commercial Energy Model. In the current versions, equipment efficiencies are usually changed only for equipment purchased for new buildings, or for replacement of retired equipment. The model assumes that all equipment has an 18-year lifetime and that all are exchanged on the 18th year. Thus, buildings of a particular age have only one age of appliances at any one time. This offers certain calculational conveniences for the model but is obviously far from realistic. Whether this makes a difference in the simulations depends on whether equipment purchases are "lumpy" in quantity and efficiency characteristics over time. If so, then these could show up at 18-year intervals. Empirical evidence from the model indicates that such uneven equipment purchase behavior is probably not prevalent. But, obviously, energy conservation programs or conservation responses would bring about some unevenness in efficiency levels which could affect future year simulations.

Two first steps are necessary to correct these decay rates.

(1) Allow different lifetimes for different appliances. (Eighteen years was taken from heating equipment.)

(2) Allow a distribution of appliance retirements.

These would of course greatly complicate the model's accounting as vintaged appliance distribution by efficiency would need to be tracked for each vintaged building type.

An important future refinement would be to model the actual retirement behavior. Equipment can and is retired before its lifetime in order to purchase more energy-efficient models. This retirement (retrofit) choice should be a function of new equipment price, fuel price, present equipment efficiency, and discount rate. A minimum life-cycle cost analysis framework similar to that used for new equipment choice is suggested for this decision-making process. There are, however, significant difficulties in using this in the

Hittman Associates, op cit, and Jack Faucett Associates, Inc., Energy Consumption in Commercial Industries by Census Region - 1974, FEA, 1977.

current model structure, and a linear programming approach outside the model might be appropriate.

g. Oil and Gas Predictions. The ORNL Regional Commercial Energy Model shows considerable error in its oil and gas projections when the model is validated with historical data for 1971-1978.* The reason for these errors is primarily that gas service to commercial customers is interruptible during fuel shortages. Oil is often used as a substitute; in fact oil plus gas have much lowered prediction errors. Prediction of these interruptions has been and will continue to be difficult.

An additional fuel availability factor may, however, exacerbate these problems -- the accessibility of gas hookups for housing constrains fuel choice. The present model does not account for these hookups directly in the fuel choice equations.

Data from the Non-residential Building Interim Energy Consumption Survey and future such surveys will collect gas hookup data. This should assist reestimations of field use equation to provide a basis for future projections.

E. Bibliography

Arthur D. Little, Inc. Solar Heating and Cooling of Buildings (SHACOB) Commercialization Report, NTIS-HCP/M 70066-01/1, 01/2, 01/3. Part B, "Analysis of Market Development." Prepared for Federal Energy Administration, May 1978.

Charles River Associates. Development of a Commercial Sector Energy Use Model for New York State, CRA Report #438. Prepared for New York State Energy Office, August 1979.

Cohn, S., et al. A Commercial Energy Use Model for the Ten U.S. Federal Regions, ORNL/CON-40. Oak Ridge National Laboratory, April 1979 (Draft).

Cohn, S. Fuel Choice and Aggregate Energy Demand in the Commercial Sector, ORNL/CON-27. Oak Ridge National Laboratory, December 1978.

**Conversation and notes from Peter Degenering, July 8, 1980, at Georgia Tech Engineering Experiment Station Seminar on End Use Models.*

F.W. Dodge. "Dodge Construction Potentials" (brochures). McGraw-Hill Information Systems.

General Electric Center for Energy Systems. "Commercial Buildings Inventory." Volume I of Commercial Sector Energy Consumption Data Base Development Project (CFES-R-78-2), June 1978.

Hartman, R. "Frontiers of Energy Demand Modelling," Annual Review of Energy. Energy Reviews, Inc., 1977.

Hittman Associates, Inc. "F.W. Dodge Data Base." Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D (Draft). June 1980.

Hittman Associates, Inc. "Nonresidential Buildings Surveys of Energy Consumption." Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D (Draft). June 1980.

Hittman Associates, Inc. "The Oak Ridge National Laboratory Commercial Energy Model." Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D (Draft). June 1980.

Hittman Associates, Inc. Physical Characteristics, Energy Consumption, and Related Institutional Factors in the Commercial Sector, HIT-630. October 1975.

Hittman Associates, Inc. "Solar Market Development Model." Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D (Draft). June 1980.

Jack Faucett Associates, Inc. Energy Consumption in Commercial Industries by Census Division - 1974. Chevy Chase, Maryland, March 1977.

Jackson, J.R. Conservation Policy Modelling Capabilities of the ORNL Residential and Commercial Models (Draft). Oak Ridge National Laboratory, February 1980.

Jackson, J.R. Energy Use and Conservation in the Commercial Sector: An Econometric-Engineering Analysis, ORNL/CON-30. Oak Ridge National Laboratory, January 1979.

Jackson, J.R., and W.S. Johnson. Commercial Energy Use: A Disaggregation by Fuel, Building Type, and End Use, ORNL/CON-14. Oak Ridge National Laboratory, February 1979.

Jackson, J.R., et al. The Commercial Demand for Energy: A Disaggregated Approach, ORNL/CON-15. Oak Ridge National Laboratory, April 1978.

Johnson, W., and F. Pierce. Energy Cost Analysis of Commercial Building Shell Characteristics and Operating Schedules, ORNL/CON-39. Oak Ridge National Laboratory, April 1980.

The MITRE Corporation. The SPURR Model: A System for Projecting the Utilization of Renewable Resources, ERHQ/2322. September 1977.

Orkand Corporation. SOLARSIM Operations Manual, TR-77W-061, July 1977.

Orkand Corporation. SOLARSIM Specification Manual, TR-77W-060, July 1977.

U.S. Department of Energy. "Energy Efficiency Standards for Consumer Products." Technical Support Document No. 5. DOE/CS/BCS, May 1980.

Westat, Inc. "Non-Residential Buildings Energy Consumption Study." Questionnaire (OMB No. 038-5-78042) for Department of Energy EIA Survey, December 1979.

Westat, Inc. "Study of Energy Consumption in Non-Residential Buildings." Survey form (OMB No. 038-5-80002) for the forthcoming Nonresidential Buildings Feasibility Survey.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

IV. BROOKHAVEN BUILDING ENERGY CONSERVATION OPTIMIZATION MODEL (BECOM)

A. Introduction

The Brookhaven National Laboratories (BNL) Buildings Energy Conservation Optimization Model (BECOM) is a major tool for evaluating policy and program options affecting technological choice and energy use to meet residential and commercial buildings energy demands. This chapter discusses the model's basic structure and presents applications in order to assess its most effective role in addressing future issues of building energy conservation policy and analysis.

Given below are a brief background to the model, its use, and a summary of the findings of this report. The two major sections of this chapter then expand on these, first with an overview of present model structure, and then with an examination of BECOM's potential applications and its basic strengths and limitations.

1. Background

BECOM is an extension of the Brookhaven Energy System Optimization Model (BESOM), designed to provide detailed disaggregation of end-use energy demands in the residential and commercial sectors. Both models are linear programming optimization models concerned with distributing specific energy supplies to points of final energy demand. Their objective is to meet the energy demands at all intermediate points at minimum cost by selecting combinations and operating levels of energy technologies with the lowest total cost.

In BECOM the choice and operating levels of the preferred technological configurations in residential and commercial buildings are the products of this minimum cost optimization. These results are used to project, analyze, and evaluate the effects on energy use of conservation actions affecting the efficiency of conventional and proposed energy-related technologies, their costs, and their fuel inputs and prices. For any designation of building stocks, fuel prices and availability, and other constraints on technological availabilities, BECOM calculates the optimal combinations of technologies to meet specified residential and commercial final energy demands. The basic model considers 25 energy conversion technologies and eight building structural technologies. These can be combined with nine residential and commercial building types and six energy end uses across four regions of the country.

The basic operational version of the model develops runs for one year (or a given time period) at a time. This version is operational at Brookhaven National Laboratories (BNL). An adaptation of this has been developed for New York as the New York Brookhaven Energy Model (NYBEM). For both of these versions, projections over several time periods require repeated runs of the model. A developmental version is in progress to provide programmed multiperiod projection capabilities. At this time neither the operational nor developmental version of the model is available except at BNL, though the operational version can be accessed through computer time sharing and cooperative efforts with BNL staff. The future transfer of the model's capability for operation by other institutions in addition to BNL is planned, but no funding to accomplish this presently exists.

BECOM has been used extensively to help analyze the policy implications of various DOE energy conservation programs. These include particularly programs related to improving energy efficiencies of energy-using equipment in residential and commercial buildings and to providing standards for increased building thermal performance. Additional applications include assessing the potential market penetration and conservation impacts resulting from the introduction or proposed support for new energy-using (-saving) designs, equipment, and materials.

BECOM is an outgrowth of the Reference Energy System and the BESOM development at Brookhaven over the last decade. The motivation and general methodology for this work is given in two BNL reports, Sourcebook for Energy Assessment and Brookhaven Energy Systems Optimization Model - Methodology and Documentation. The basic description of the present BECOM model is documented in Carhart et al., 1978, The Brookhaven Buildings Energy Conservation Optimization Model. The Least Cost Energy Strategy, Technical Appendix, Carhart, 1979, provides an illustration of BECOM analysis for major energy conservation measures.* The work is ongoing, and there have been various minor updates and revisions of the model to meet the requirements of specific applications.

These documents, together with discussions with the authors of the model and with BNL scientists and DOE planning and programs staff, form the basis for the analysis that follows.

**Additional summary information on the model structure, policy variables, model inputs, outputs, data sources, and accessibility are introduced in an earlier publication, Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, Section B, "BECOM."*

2. Summary of Findings

BECOM provides a linear programming framework for analyzing and quantifying the direct impact of energy conservation policies and energy prices on the flows of energy within the residential and commercial buildings sector. The focus of the model is on the least-cost choice of energy conserving buildings, structural and energy conversion technologies which satisfy the sector's demand for energy sources. This permits analysis of government policies and programs that promote implementation of the technologies or regulate their acceptance. These may then be evaluated by specific building types and end use on the basis of fuel use and savings, and of technology penetration rates.

a. Policy Variables. Policy variables which can shape the technology choice and direct the model toward specific energy use and/or technologies include:

(1) Prices of energy inputs

(2) Capital costs for buildings structural and equipment conservation investments

(3) Efficiency levels for structures and equipment

(4) Energy supply and demand constraints.

b. Current Applications. Some of the buildings energy conservaton issues and program areas for which BECOM can provide information include:

(1) Energy conservation retrofit for buildings. All existing structures are candidates for retrofit in the model; the comparison of fuel consumption (heat loss) in existing buildings to the alternative annualized purchase price plus reduced fuel use due to upgraded installations and materials determines the retrofit decision.

(2) Appliance retrofit. Early retirement of existing energy conversion devices is also determined by comparing existing equipment fuel consumption to purchase and operating cost of their possible replacements.

(3) Thermal performance standards for new buildings. These are represented by contraints or specific building technologies which can be considered for the least-cost solution.

(4) Energy efficiency standards for appliances. Similiar to the thermal performance standards, these constrain the choice of technologies available to convert energy into end use services. The retrofit replacement choice in the model can also be affected by these standards.

(5) Fuels pricing policies. These raise operating costs and provide incentive for higher cost but higher efficiency technologies to be found cost effective.

(6) Tax credits, low interest loans, and subsidies. These lower the effective annual capital costs of targeted conservation technologies.

(7) Technological innovations. Market penetration for new technologies can be promoted as subsidies or tax credits for research, development, and implementation which raise new technology efficiencies or lower their capital costs.

c. Extensions and Limitations of BECOM for Specific Energy Conservation Issues. BECOM is an excellent tool for investigating certain aspects of the roles and determinants of technology choice for buildings energy conservation objectives. There are a number of areas, however, where the current specification or use of the model could limit its application for energy conservation analyses. Some of these are listed below and, from these, an enhanced role for BECOM in energy policy analysis can be suggested.

(1) Behavioral Analyses and Demand Forecasting. BECOM is not a demand forecasting model in a sense comparable to the ORNL residential or commercial energy models. Price changes are evaluated only as they affect the least-cost paths; otherwise, behavioral prices and income responses are not analyzed. Least-cost behavior may not reflect actual consumer behavior, and thus while indicating policy-relevant information, the "forecasts" could be misleading.

Some of these behavioral responses might be anticipated exogenous to the model by the BECOM analyst. Endogenous to the model, the model's discount rate can be used to reflect actual consumer preferences for future energy conservation savings and thus provide "simulated" rather than "optimized" forecasts. Modification to allow the discount rate to vary, for instance, across building types, regions, or end uses would simulate a still further range of behavior. With this, changes in credit term and provisions for energy credits and conservation awareness programs could also be better analyzed.

(2) Buildings and Over-Specific Disaggregation. Most published analyses with BECOM have used the model's originally specified levels of buildings disaggregation. But the model disaggregation can be expanded beyond this by defining building types within the existing protypical building categories. Office buildings, for instance, could be divided into public and private, with the same reference building descriptions but potentially different technology levels and operational characteristics. Policy measures could then be targeted to more specific building categories and, if the discount rate were also permitted to vary by building type, this could be used to reflect building- or occupant-specific behavior with such diaggregation. Potential categories for additional analysis could include owner-renter status, master metering status, income levels of occupant, and federal, state, and insitutional building conservation measures.

(3) Linkages to Other Models. BECOM is itself constrained to analysis of energy flows within the buildings sector. Fuel inputs to the sector and the sector's final demands are fixed for the analysis. It is possible, however, to link BECOM to other models that extend its implication to other energy and economic sectors. For example, use of BECOM with the BESOM model can provide an interface to the rest of the energy sector; the BNL/Dale Jorgenson long-term energy economic model can provide prices and final demand inputs to BECOM from the rest of the economy, while the Illinois input-output model linked to BESOM can translate BECOM-derived efficiencies and energy flows into requirements for goods and services in the rest of the economy.

(4) Shadow Prices. Shadow prices are an output of a linear programming framework such as that used in BECOM. These are the dual variables associated with the constraints of the model. For BECOM they give the opportunity cost (in terms of the minimum cost solution) of changes in fuels supplied to the sector, demand requirements, or technological constraints on the model. There has been little use of the BECOM shadow prices for policy analysis because applications have not focused on varying the constraints. However, if, for example, a decision were being considered to cut back on a fuel supplied to the building sector, then this choice could be guided by the shadow prices associated with each fuel supply constraint; a shadow price would be indicative of the value of the change in availability of that fuel as it is allocated in least-cost manner with the building sector technologies to meet the final demands.

(5) Data and Parameter Updates. BECOM currently uses 1975 as a base year for its analyses. More up-to-date base year information would increase the relevance of the model for current policy analysis, since it is that year's technologies, costs, and fuel use pattern against which the model determines projected levels of investment and technologies. An update to 1977 is to be undertaken jointly by BNL and Oak Ridge National Laboratories (ORNL). Provisions for future updates and for synergistic use of the Oak Ridge demand models forecasts with BECOM least-cost scenarios would directly facilitate the role of BECOM to complement the present use of ORNL models in energy policy analysis and forecasts for DOE.

(6) Multiperiod Analysis. BECOM provides its optimization for only one time period at a time. Multiple-period analysis requires multiple runs of the model, with respecification for each later period's technologies, new and existing building stock, efficiencies, etc. A more standardized and systematic approach is needed in the form of a time-stepped version of the model. Problem areas in doing this include: (a) treatment of consumer knowledge or expectation of future prices and technologies as these change from one optimization period to the next; and (b) the BECOM accounting for housing and appliance vintages from one period to the next.

(7) Model Transferability and Accessibility. Despite its value to energy planners, BECOM is used very little except by BNL staff and the model's developers. To assist the model's broader application, several steps are needed: (a) the computer model should be transferred to run at other installations; (b) the model should be documented in a users' manual for step-by-step explanation of setup, runs, data inputs, etc.; and (c) at the cost of some flexibility, various analysis and input procedures should be standardized, such as those multiperiod analyses, and definition of building types.

(8) Additional areas.

(a) Building and Appliance Age and Retirements. There is no age or vintage specification for buildings or appliances in BECOM. The model assumes these have fixed lifetimes and are retired as a fixed annual percentage in inverse proportion to their lifetimes. These simplifications ease the model accounting at the cost of precision. Generally, major problems and discrepancies will occur only when disproportionately large numbers of investments are made at one time. The pragmatic solution is simply to be observant of such occurrences.

(b) Salvage Values of Equipment. BECOM considers as sunk costs the value of existing equipment. For equipment which does have salvage value, the number of calculated retrofits are underestimated; the salvage value should be subtracted from the new investment costs. However, without the model's accounting for equipment age and purchase date, general attribution of salvage value would be difficult; but this could be done for specific appliance categories where the salvage value might be significant.

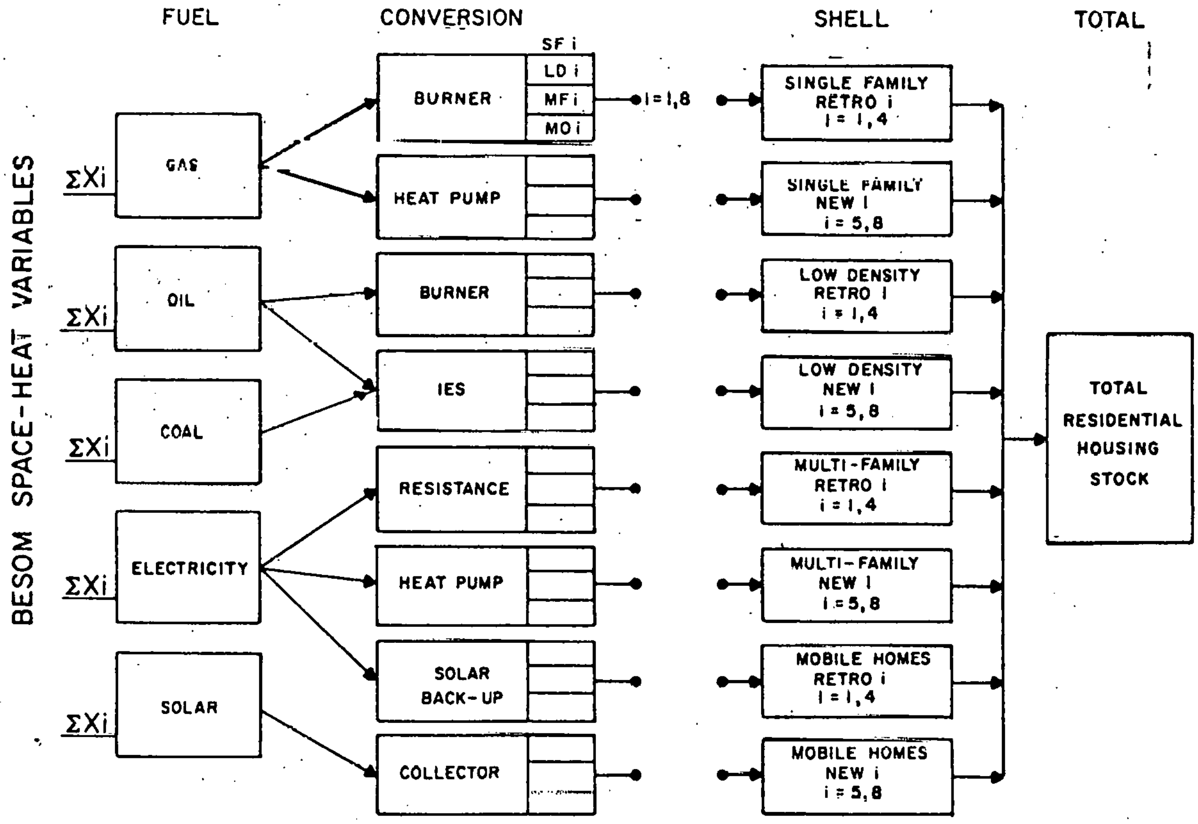
B. Overview of the BECOM Model

1. Basic Model Features

BECOM is a representation of the technological and economic cost features of the energy flows within the commercial and residential buildings sectors. The model selects combinations of energy-consuming technologies according to various cost-minimizing criteria within a linear programming framework. For any designation of building stocks, fuel prices and availability, and other constraints or technological availabilities, BECOM calculates the optimal combination of available energy-using technologies to meet the specified residential- and commercial-sector final energy demand. This is expressed in terms of levels of market penetration of specific technologies. The basic model considers 25 energy conversion technologies and eight building structural technologies as these might be combined in nine residential and commercial building types and six energy end uses across four regions of the country.

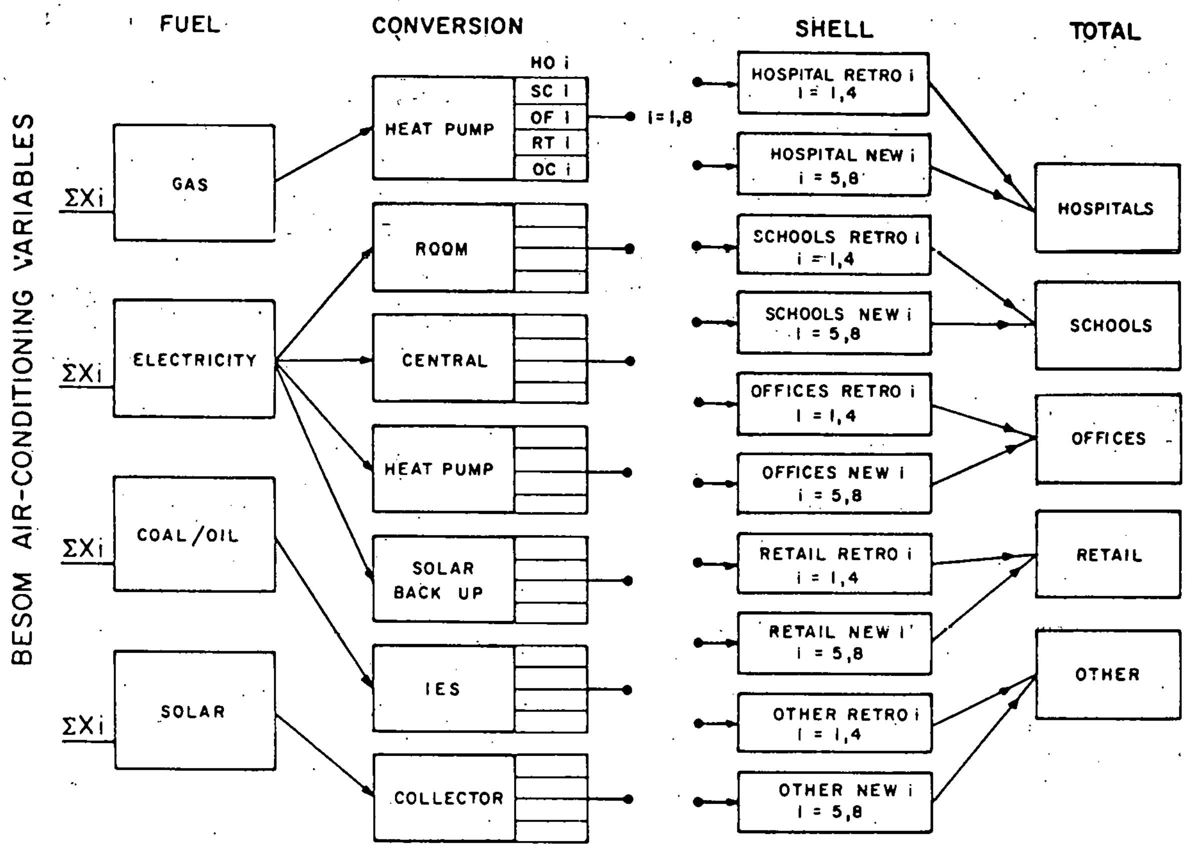
BECOM is designed as a linear programming optimization model. Mathematically, the model is formulated as a modified transportation/transshipment problem concerned with distributing energy from specific supply centers to points of demand. The objective is to meet energy demands at all destinations at minimum cost. The model accomplishes this by determining the lowest-cost technology that can be used to the fullest extent possible to meet these energy demands.

Figure IV-1 provides an example of the structure of energy flows and conservation technologies for residential space heat for each region. Figure IV-2 provides a similar example for commercial-sector air conditioning. The BECOM structure for other end-use applications in the residential and commercial buildings sectors is similar to those shown in these figures.



Source: Carhart, S., et al. The Brookhaven Buildings Energy Conservation Optimization Model, p.8

Figure IV-1. BECOM: Structure of Residential Space Heat



Source: Carhart, S. et al., The Brookhaven Buildings Energy Conservation Optimization Model, p.12

Figure IV-2. BECOM: Structure of Commercial Air Conditioning

The energy demands described by BECOM are energy requirements given for each specific market. For the example in Figure IV-1, in the residential sector, the space heating requirement for single-family homes in the Northeast is one specific point of energy demand. The extent to which any given technology can be utilized to meet this energy demand, that is, its market penetration, is determined in the model by the existing constraints on its use. These constraints are defined through equations which establish the limitations of resource availability that affect the production or implementation of a technology. These and other constraints are described more fully in 3.

BECOM may be run simultaneously with or independent of BESOM. BESOM optimizes technology choice and energy flows for a detailed representation of the energy supply system; BECOM further disaggregates the fuel demands for optimized flows in the buildings sectors. If BECOM is run independently of BESOM, assumptions concerning the availability of fuels must be made, which serve as the information on energy supply for the residential and commercial buildings. When, instead, BESOM is used to provide fuels supply data to BECOM, the constraints of both models are included in the analysis.

The analysis uses nine prototypical or reference buildings (four residential, five commercial) for which heat losses or service demands are calculated from accepted industry and architectural procedures. These are conceived for prototypical cities in each of four regions of the country with appropriate heating and cooling degree days. Fuel demands are then calculated using average utilization efficiencies in the building. Costs and efficiency changes postulated for representative (policy-determined) technology measures then permit the model to calculate and compare optimal (usually optimal for the least-cost objective) configurations of investments and utilization of all technologies to meet the given final end-use demands for energy.

2. Sectoral Detail

BECOM provides end-use detail for residential and commercial buildings. It explicitly models 25 energy conversion technologies, such as burners, heat pumps, electric motors, condensers, blower fans, and light bulbs and other lighting equipment; and models eight structural technologies such as the building envelope, pipe and heater insulation, and appliance performance levels.

These energy conversion and structural technologies can be used by nine residential and commercial building types. Each of these residential and commercial building categories includes two subcategories: retrofit (existing) buildings and new construction. The residential building types include:

(a) Single-family detached homes

(b) Low-density dwellings

(c) Multifamily high-rise buildings

(d) Mobile homes.

Commercial building types include:

(a) Hospitals, including all health care facilities, private and public

(b) Schools, including classrooms, laboratories, and libraries

(c) Offices, including general office space; state, local, and federal administration buildings; and banks

(d) Retail, including malls and general mercantile buildings

(e) Miscellaneous, including hotels, motels, churches, service stations, recreational facilities, and other commercial buildings not included in the above four categories.

In the basic version of BECOM, each of these residential and commercial building types is analyzed for each of four regions and each of six energy end uses. The four regions are:

(a) Northeast

(b) North Central

(c) South

(d) West.

The six energy end uses include:

(a) Space heating

(b) Air conditioning

(c) Water heating

(d) Cooking

(e) Appliance loads

(f) Illumination loads.

Using the building structures and the regional and end-use detail in the residential and commercial sectors described above, the BECOM energy demand analysis considers allocations of a number of fuel types. Data concerning the availability of these fuel types are obtained either by assumption and policy constraints or through the use of the BESOM energy supply analysis. These fuel types include:

(a) Natural gas

(b) Oil

(c) Coal/fossil fuels

(d) Electricity

(e) Solar.

The analysis of the energy flow is accomplished through a detailed flow network that represents technologies in buildings in one of the four regions, and an aggregated demand representing the energy requirement in the other three regions. This is done for each region so that a national energy flow projection is developed. Outputs are then given at three levels of aggregation:

(a) Energy demand by building type, including both retrofitted and new buildings, by fuel conversion technology

(b) Summation of energy flows, done separately for residential buildings and commercial buildings, by fuel conversion technology

(c) Net energy demand for each sector and region, by fuel and end use.

In addition to these outputs, the investment (in 1975 dollars and in units installed) in energy-related devices and structures is summarized during the period from 1976 through the case year.

3. BECOM Analytical Structure, Constraints, and Data Inputs

a. Heuristic Description. The equations for the BECOM structure are given in detail in Carhart et al., 1978, The Brookhaven Buildings Energy Conservation Optimization Model. The following will summarize these in energy-economic terms. Figure IV-3, together with Figures IV-1 and IV-2, provides a simplified illustration of the model flow.

(1) Energy Flows. In the model a commodity called energy can be visualized as flowing or being transferred from its initial fuel sources (fixed supplies) to meet its final building service demand requirements (warmth, hot water, etc.) through various paths which involve energy conversion devices and building or equipment structural technologies.

(2) Energy Efficiencies and Conservation Investment Costs. As energy is employed by a conversion device or in a related structural shell, a percentage is expended or lost. These operating or fuel costs are noted in the model by the conversion efficiencies and structural heat loss efficiencies. Purchasing new devices or structures, or making conservation retrofit investments for existing ones, can increase these efficiencies at the expense of added capital costs. The model evaluates the cost of these investments as the annualized payments necessary to pay off the purchase and installation price.

(3) Optimum Choice of Technologies. Decisions determining which of the available conversion devices and structural shells to employ are made using a least-cost optimization procedure. Given the final energy services demanded, the available fuel supplies and other constraints on choices (see below), the optimization procedure chooses the combinations of equipment and structures for each building that yield the lowest total fuel plus annualized capital costs. In effect, this means that investments in energy-conserving equipment and structures are purchased up to the point where the increased annualized capital costs are just matched by the lower fuel cost resulting from the increased efficiency.

b. BECOM Constraints. From all conversion devices, structural shells, and associated costs and efficiencies input to the model for a particular market, BECOM's linear programming algorithm chooses the lowest-cost technology combinations and implements these to the maximum level permitted by the system constraints. These constraints are detailed below.

FLOW:	ENERGY SUPPLIES →	CONVERSION DEVICE →	STRUCTURAL TECHNOLOGY (THERMAL SHELL) →	FINAL ENERGY SERVICE DEMANDS FOR BUILDINGS.
EXAMPLES:	OIL, GAS, ELECTRICITY, SOLAR, OTHER	BURNER, HEAT PUMP, ETC.	BUILDING THERMAL ENVELOPE, WATER HEATER INSULATION AND PIPES, ETC.	ROOM TEMPERATURE, HOT WATER, LIGHTING, ETC.
COSTS:	FUEL PRICES	FUEL CONSERVED; CAPITAL COSTS OF EQUIPMENT PURCHASE	ENERGY LOSSES (FUEL EQUIVALENT); CAPITAL COSTS OF INVESTMENTS AND IMPROVEMENTS	MINIMUM TOTAL COST OF FUEL COSTS PLUS ANNUALIZED CAPITAL COSTS

Figure IV-3. Simplified BECOM Flow

(1) Demand Constraints. These provide the final demands that must be satisfied by the energy flows of the model. They are given for each end use and building type and represent a specially defined term, "basic energy demand." This is the amount of energy required to support an end-use activity (space heating) at levels determined as nominal in 1975 for that end use and reference building or thermal shell. For instance, the energy flow for air conditioning of offices must equal the theoretical air conditioning load for the total stock of office buildings.

(2) Supply Constraints. These are supplied either from BESOM results or given exogenously. They limit the amount of fuels that may be used in a planning year either in total use or for a specific purpose within the residential and commercial sectors.

(3) Minimum Residential Stock of Buildings. This assures that the model's energy accounting provides for the actual number of buildings. For example, for mobile homes, the number of mobile homes heated by electricity in any given year must equal the number that actually existed in the base year minus the number of removals from the base year to the year in which the analysis is performed.

(4) Fuel Market Shares for New Construction. Exogenous projections of new housing starts by fuels provide the constraints for the market shares of oil-, gas-, electric- and solar-heated housing or commercial units. These generally provide bounds within which the model can vary the fuel choice for minimum cost.

(5) Seasonal Load Balance. This constraint ensures that for each building type, the heating, air conditioning, thermal, and appliance loads for each shell, such as hospital building thermal envelopes, are balanced.

(6) Seasonal Operation Constraints or Heat Pumps. Heat pumps are constrained to a ratio of heating and cooling equal to the ratio of heating/cooling loads for the specific shell, building type, and region, such as multifamily building envelopes in the North-Central region.

(7) Backup Requirements for Solar Energy Uses. These constraints reflect energy requirements which protect against conditions when insolation is insufficient to provide energy from solar collection and storage alone.

(8) Solar Space Heating Use with Solar Air Conditioning. This recognizes that solar air conditioning is never used by itself.

(9) Solar Hot Water Heating Use with Solar Space Heating. This ensures that buildings that employ solar space heating derive their hot water from the same system.

c. Input Data. The BECOM structure is determined by the energy flow network for building energy use and by the optimization criteria and the constraints to demand supply and technical structure. These were introduced above. The final element necessary for BECOM buildings conservation analysis is the performance and cost data used to quantify the analysis. Major data categories include:

(1) Building stocks

(2) Theoretical building loads

(3) Shell or structural efficiencies

(4) Conversion device efficiencies

(5) Technology costs

(6) Building market shares by fuel.

The major data source for BECOM has been the Arthur D. Little (ADL) data base for buildings.* These evolved from the ADL Project Independence studies where prototypical buildings and their climatic conditions and energy loads were developed.**

(1) Building stocks. These include inventory data for the year 1975, removals and new construction for years 1976 to 2000, and total building stocks. Residential building stock by four types is given in number of units; commercial building stock by five types is given in number of square feet.

*A compilation of much of the earlier and recent ADL buildings work can be found in Glesk, Martin, Potential for Energy Technologies in Residential and Commercial Buildings, DOE/PE/03871-T1, Arthur D. Little, Inc., November 1979, and Residential/Commercial Market for Energy Technologies, DOE/PE/03871-T2, Arthur D. Little, Inc., August 1979.

**For a brief summary of earlier ADL work see Section G of Hittman Associates, Inc., Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, June 1980.

(2) Theoretical building loads. These are given for different building types and different climatic conditions in each of the four regions, in the following categories: space heating, air conditioning, hot water, lighting plus power, and auxiliaries for commercial buildings. These provide the reference loads for each structure from each conversion device under various load conditions.

(3) Shell efficiencies. These are the percentage improvement in structural integrity over a nominal 1975 value that can be expected from implementing certain changes in structural technologies in building thermal envelopes. These may be varied as new structural technologies are introduced.

(4) Conversion device efficiencies. These are the percentages of delivered energy which can actually be applied to the theoretical building loads.

(5) Technology costs. Include are the costs of conversion devices and materials and installation of structural technologies, both for new buildings and retrofit applications.

(6) Market Shares. These provide by building type the bounds the optimization can select for fractions of fuels, technology costs, and performance.

C. Applications and Extensions of BECOM For Buildings Energy Conservation Analyses

BECOM provides a means of measuring and analyzing the direct impacts of conservation policies and energy prices on energy demand to meet given levels of energy services in residential and commercial buildings. Since a large number of structural and conversion technologies are modeled separately, it is possible to analyze the interaction of various combinations of these until the preferred (minimum-cost) configurations are identified. BECOM structure explicitly models the determinates and effects of technology choice in conversion devices and structural shells and thus permits analysis of government policies and programs to promote their implementation or regulate their acceptance. The policies and programs can be evaluated from the optimized results giving fuel use and savings, investment levels, and the technology penetration rates; each of these is computed in aggregate and for specific building types and regions of the country.

The following discussion identifies the basic application areas for the model, the policy variables best suited to these applications, and some of the building energy conservation issues and program areas for which BECOM can provide information. Some current limitations of the model are outlined; in light of these, an enhanced role for BECOM in energy policy analysis is then suggested.

1. <u>General Application Areas</u>

The entire BECOM structure can be interpreted as focusing on the choice of energy-conserving technologies for new and existing structures and conversion devices. Most applications can thus be translated first into factors that influence these technology choices and, with these, into the resulting changes in fuels use and investments. Applications can be generally classified as directed toward (a) technology assessments or (b) conservation analyses, although naturally the two overlap.

a. <u>Technology Assessment</u>. For technology assessment, the potential market penetration of new and existing technologies or of combinations of these conversion and structural technologies are investigated. Product research, development, and marketing for new technologies which offer improved efficiencies and/or lower cost can be evaluated in terms of their acceptance and purchase by household and commercial establishments. Both the levels of total penetration and the identification of particular building types and regions with higher market penetration can then help the BECOM user target productive investments or research. These results also indicate whether expected improvements in efficiency or costs would help the product compete with other technologies.

A particular value of these market assessments is that, in comparing all feasible combinations of conversion devices and structural technologies, the market choice is based on the cost and energy saving of the best overall combination; this avoids the potential double counting of energy gains that could occur if each technology were evaluated separately for energy savings.

b. <u>Energy Conservation Analysis</u>. In these applications, analysis is directed toward investigating ways of lowering energy consumption in buildings by affecting the choice of the technologies which convert or contain the energy used to satisfy the basic energy needs (final service demands) of the buildings and their occupants. Changes in such factors as prices, investment taxes, and efficiency and thermal performance standards influence the combination of structures and conversion devices, and thus the efficiency at which energy inputs to buildings are carried into the final services. In turn, these are translated into energy (and specific fuels) consumed and into specific technology investments.

2. Generalized Examples of Technology Choice in BECOM

Two generalized descriptions will serve as background for more specific policy applications. These descriptions follow directly from the basic model structure discussion given in Section B.

a. Structural Technology Choice for New and Existing Buildings. This involves the choice of investments in structural technologies to enhance thermal performance of the external shells of buildings or of the shells internal to the building that can be used to contain energy outputs from various conversion devices (e.g., pipes, ducts). Such investments are made both for construction of new buildings and for retrofit of existing structures. In either case BECOM models the investment decision as a function of shell thermal performance characteristics (floor, ceiling, and wall insulation, caulking, window area and glazing, duct construction, etc.) and their annualized investment costs. These are then combined with the various costs and efficiencies of heat-generating (or cooling) devices in the building (burners, heat pumps, hot water heaters, etc.) in order to supply the required thermal energy services of the building at least annual cost. The future fuel expenditures and the investment charges annualized over the product lifetime are evaluated using a given discount rate which reflects average residential and commercial time preferences. Any change in fuel market shares or fuel mix selected by the model for new construction is bounded by upper and lower limits which reflect BECOM user-determined construction trends or housing projections.

For structural conservation investments in new buildings, the number of potential installations are estimated by projecting housing and commercial building requirements and comparing these to the existing building stocks and the number of demolitions. For each new structure the final thermal energy services required are predetermined in the model by the building type, location, and the assumed final consumption practices (e.g. the desired inside temperature for new retail building in the Northeast). Investments to reduce thermal losses are then chosen from a given set of existing and expected technologies. Integral to this conservation investment choice are the input prices of materials and installation in new buildings, their resulting thermal efficiencies, and the existing or projected prices and availabilities of fuel supplies. The selected least-cost technologies then permit the model to calculate the total investment costs and fuels consumed.

For existing buildings there is generally no predetermined number of buildings requiring the new investments (unlike the number of new buildings under construction, which is given exogenously). Instead the BECOM linear programming algorithm effectively takes all existing structures as candidates for retrofit and considers all added investments in energy-conserving materials and installations and the resulting reduction in heat loss that could occur. The annualized fuel and investment costs of using each of these new technologies are then compared with the status quo annual fuel costs of the existing structure without retrofit. Retrofit investment is undertaken where the new investments would lower the total annual costs. Thus, unlike most other macroanalytic building energy conservation models, the retrofit decision is endogenous to the model.

b. <u>Technology Choice for New and Existing Energy Conversion Devices</u>. The investment decisions to purchase new appliances to meet the demands of new households or buildings or to replace old equipment are very similar to the structural shell investment decisions discussed in 2. a. above. The efficiencies and investment costs of the possible devices to supply a specific energy service (e.g. lighting or heating) are combined, where appropriate for the thermal devices, with the costs and efficiencies associated with the option for building thermal shells (as in a. above). Given the purchase prices, the availability and prices of fuels, and the efficiencies of specific technologies, BECOM chooses configurations of new and existing equipment which meet the required energy services at least cost. Any changes in fuel market shares or fuel mix resulting from equipment selection are bounded in the model by upper and lower limits reflecting exogenously specified construction trends or housing projections.

Appliance demand is determined by those devices needed in new housing, plus the replacement for those retired at the end of their economic lifetime, plus early retirements. For the latter case, replacement of existing appliances before the end of their economic lifetime, BECOM assumes that the costs of all previous purchases are "sunk costs" and do not enter into future cost comparison. Thus the "retrofit" decision to scrap an existing appliance and to replace it with a new one is the result of the comparison of the annual fuel costs for the existing equipment against the sum of the annualized purchase price plus fuel cost for available replacement technologies. The appliance retrofit decisions, like building retrofits, can thus be made fully within the model.

3. Policy Variables for BECOM Applications

A variety of variables are available in the model which can affect or shape technology choice and direct the model toward analysis of specific energy use or technology penetration objectives. These policy variables include:

(a) Prices of energy inputs (fuels) which can be altered by tax and pricing policies to change present and future operating costs for each technology configuration.

(b) Capital charges for building types which can be altered by various builder and purchaser tax incentive and subsidy policies to modify the tradeoff of the materials and installation investment costs versus operating costs for each building technology.

(c) Equipment costs which can be altered by various producer or purchaser tax incentives and subsidy policies to modify the investment cost versus operating cost of different types of energy equipment in buildings.

(d) Efficiency levels for structures or equipment which can be altered by promotion of R&D and commercialization programs or by imposed efficiency standards (constraints) in order to modify market penetration levels of various technologies.

(e) Limits on the constraints, such as energy demand or supply limitations and environmental controls, which allow the changes in regulatory policies to be assessed so that the chosen technologies can be implemented at new levels.

4. Applications to Energy Conservation Issue and Program Areas

a. Thermal Performance Standards for New Buildings. These are represented in the model by constraints which require or prohibit building technologies in specific building markets. This effectively limits the choice of technologies that are candidates for BECOM analysis to those equal to or above the standard's efficiency or thermal performance criteria. The optimization procedure then selects the combination of conversion technologies and the standards-constrained structural technologies meeting the least-cost criteria while satisfying the required final energy demands. The model results indicate the amount of fuels used (and thus fuel savings relative to a no-standards case) and the levels of investment undertaken to increase building thermal integrity.

The levels of market penetration of the individual technologies can indicate whether the standards constraint did actually apply or whether, for the discount rate used in BECOM, the residential and commercial customers would actually select technologies more efficient than the standards.

b. Energy Efficiency Standard for Appliances. BECOM analysis of these is very similar to the above analysis of the thermal performance standards. Energy efficiency standards for appliances are represented by constraints which require or prohibit appliance technologies in specific building markets. These limit the choice of technologies that can be considered for the least-cost solution. However, unlike building structure investments, the consumer also has the option to scrap the less efficient appliance and purchase a new one, as discussed in the example 2b above. Thus the standards also apply to "retrofit replacement" decisions. For a given end use, the set of all conversion devices of greater efficiency than the standard are considered for replacement of existing devices. Those with the lowest total annual cost below the fuel costs of the existing device will be selected for retrofit replacement by the BECOM linear programming algorithm.

c. Fuels Pricing Policies to Encourage Energy-Efficient Structures and Appliances and Thus Reduce Energy Use. Increases in fuel prices which can be varied by regions and sectors alter the relative value and thus the choice of various energy conversion and structural technologies in the model. Higher fuel prices mean higher operating costs and thus may tip the tradeoff of efficiency versus purchase price toward higher efficiency. This is true both for new buildings and appliances and for decisions to retrofit (structures) or replace (equipment) to achieve the higher efficiency levels. The input prices can be targeted to specific building sectors in order, for instance, to investigate the impact of controls on key fuels or fuel use in specific buildings (e.g. electric rates for commercial space heating). The net changes in fuels use to meet the given final demand are found by comparing fuel consumption in the base case where input prices were not varied to the scenarios where prices change.

d. Investment Tax Credits, Low-Interest Loans, and Grants or Subsidies for Building and Appliance Energy Conservation Investments. These factors change the economics of the technology evaluation as they lower the effective annualized capital costs of the targeted technologies. As policy instruments they can be technology-specific for each building subsector and region. This is important since the mechanisms are not always specifically targeted reductions in technology costs but can depend on the building and owner characteristics. Tax effects, for example, are likely to be different depending on the building type and how this might reflect the tax status of the occupant/owner. Similarly, interest rate decreases and adjustments in the terms of the loan change the effective annualized capital charges for investments relative to that calculated using the given BECOM discount rate. Grants and subsidies more straightforwardly alter the investment cost.

e. Promotion and Introduction of Technological Innovations. BECOM permits the explicit investigation of the possible results or rationale for government sponsorship or subsidies and tax credits for research, development, and implementation of energy-saving technologies for buildings. Introduction of a new technology to the set of available technologies for a specific end use and building (for example, gas heat pumps designed for large commercial buildings) would permit the model to calculate its potential market penetration and the resulting change in energy use. If the new technology is not selected by the model's least-cost criteria, then the model may be used to investigate what measures would bring about the market penetration and/or the desired reduction in energy use. Higher efficiency goals or lower sales prices can be translated into increased R&D support or additional production or purchase subsidies or tax credits.

5. Extensions and Limitations of BECOM for Specific Energy Conservation Issues

As it currently stands, BECOM is an excellent tool for investigating many aspects of the role of technology choice upon buildings energy conservation objectives. There are a number of areas, however, where the structure or current specification of the model places limits on its applications for energy conservation analysis. A number of these areas are given below with suggestions, where possible, for changes that would strengthen the potential contribution in future policy and planning studies.

a. Behavioral Analysis and Demand Forecasting. BECOM uses a linear programming framework which can assemble alternative combinations of energy-related technologies to meet final energy demand requirements at least cost. As such it is definitionally, and in many cases in practice not applicable as a demand model in a sense comparable, for instance, to the Oak Ridge National Laboratories' models of residential and commercial energy demand*. Except to the extent that consumer behavior is embodied in BECOM's normative least-cost energy

**See Chapters I and III of this report for a discussion of these two models.*

path criteria, intermediate technology investment and fuels demands in BECOM are based on technological and fixed cost factors. There are no explicit consumer demand equations or price and income elasticities for energy-produced services.

Thus while the model is better suited than most engineering-economic models (such as those of ORNL) to model explicitly the cost-effective tradeoffs of equipment or structural capital cost versus energy efficiency, it is not strictly applicable to demand forecasting. Increases in energy prices, for instance, are modeled by BECOM to increase the cost savings of more efficient technologies and therefore increase the likelihood that such technologies will be selected by the linear programming algorithm. This omits, however, the consumer's additional operational response to increase energy prices, which is to directly reduce final demands for the now more expensive energy services. (Such operational changes might include setting back the thermostat in winter and living with cooler comfort levels, or reducing lighting use and levels.)

Furthermore, in most current applications, BECOM is attempting t model least-cost behavior toward buildings energy decisions instead of actual behavior. To the extent that consumers have criteria different from its least cost, (e.g. desire luxury over function), have different weighting factors (i.e. different discount rates), or cannot achieve the least-cost solution (because of lack of informatin, credit market imperfections, etc.), a forecast from BECOM will be in error.* There are, however, several ways in which this can be mitigated.

(1) Behavioral Responses. To some extent, change in final energy service demands and their resulting behavioral operational charges can be estimated external to BECOM and used to exogenously change the input final demand requirements.** However, the consumer should be basing the consumption of energy services on the price of the actually delivered energy services, in addition to the direct effect of fuel prices. The delivered

*Evidence from ORNL studies (O'Neal et al., 1980, and earlier work by Hirst and Carney, 1978) indicate wide divergence from the minimum life-cycle cost choice and variations in this between fuel types and appliances. Recent studies such as that by Hausman, 1979, suggest that these differ by individual socioeconomic characteristics as well.

**Estimates of the short-run operational elasticity can be found in ORNL studies by Cohn, et al., 1976, for the residential sector and applied in Hirst and Carney, 1978; and in Cohn, 1978, for the commercial sector, applied in Jackson, 1978.

energy services price can also be altered by the consumer's choice of technology and efficient fuel use and by the coice of fuels. The consumer's choice of the level of final energy services is thus jointly determined by fuel price, efficiency level, and fuel choice. Any exogenous specification of final demand requirements is not likely to capture fully the simultaneous interaction of these three factors (unless, for instance, the change is mandated, or if the model is run in a policy mode to explore the effects of such a change in final demands on technology choice and fuel use).

(2) Discount Rate. BECOM does include a long-term discount rate that reflects the present value that consumers (or society) place on goods and services or on costs that will occur in the future. In the model this discount rate is used to provide an annualized capital cost for equipment or structural investments. In most BECOM policy applications this rate is assumed to represent society's rate of time preference.* However, the rate could also be used to reflect the discount rate implicit in actual buildings energy conservation decisions.** To the extent that an average "implicit discount rate" can be estamiated for future conservation decisions, this can be used to "adjust" the market to simulate actual behavior.# Changing this rate in the model requires only the change of one parameter value.

If, in addition, the model were modified to permit the discount rate to vary by building type; by structural improvements, appliance technology or their end use, and by region, then it would be possible to simulate more precisely a broader range of consumer behavior and responses to energy conservation initiatives. Two examples, of the usefulness of this for policy analysis are given below.

**A public sector discount rate of 5 percent in real terms was used for BECOM runs in The Least Cost Energy Strategy by Carhart et al., 1979.*

***BNL documentation of such applications was not available to the author of this report, but discussions with BECOM co-author Dr. Carhart of the Mellon Institute indicate that such applications have been explored.*

#Dr. Carhart indicates that a "back of the envelope" calculation of a 45 percent discount rate would bring BECOM least-cost results for 1978 into line with actual buildings energy conservation investments. This rate is similar to that found in the ORNL residential model.

(a) Credit Term and Credit Availability. To the extent that these are tied to specific conservation technologies or building types, programs to provide these favorable terms could lower the relevant implicit discount rates. More efficient but costlier technologies would then be more likely to penetrate the market.

(b) Buildings and Conservation Information and Assistance Programs. Lack of consumer awareness of potential for energy conservation savings, poor information and uncertainties about measures to be taken, and imperfections in the credit markets are factors that can impede selection and implementation of cost-effective energy conservation investments. These factors could be reflected in a higher measured implicit discount. Efforts to lower these barriers, such as programs for energy audits, residential conservation services and awareness, and utility assistance to consumers, could be simulated in lower discount rates. These would be indicative of increased incentives to value the future energy savings that result from higher equipment and structure efficiencies.

b. Building- and Owner-Specific Disaggregation. BECOM currently specifies nine building types for both existing and new buildings. (The criteria for existing and new buildings generally depends on whether they were built before the base year of the projection, initially 1975). Each prototypical building type used in energy analysis can also differ for each of the four regions of the country in which it could be located. Currently there are potentially 9 (buildings) x 2 (new and existing) x 4 (regions) = 72 building types, though not all regional variations are used.

Most published analysis with BECOM has been restricted to the model's originally specified levels of buildings disaggregation. But the model structure can actually be expanded beyond these. Integral to the current BECOM computer program is the procedure to accept additional disaggregation within the existing prototypical building categories. For example, the office building category could be divided into public and private components. Limitations to such disaggregation are found in the degree to which the fixed prototypical building specifications are appropriate for specific uses, and the degree to which data to specify additional categories are available. Such data would include initial and projected building stocks, their technology levels, and market shares of fuels for existing buildings and new construction.

The reference or prototypical building types used by BECOM are not easily respecified because of the large amount of data on energy use and new technology characterizations that are embodied in them. Where these are not representative of a building type to be analyzed, the model could accept new prototypical building specifications developed, for instance, from buildings energy use analysis based on DOE-2 model residential and commercial building runs.

For any new building category disaggregation, BECOM would continue to select the cost-effective choices of technologies for retrofit and new purchases that meet the final energy demand requirement. Tax incentives, subsidies, efficiency standards, and new construction technologies could then be targeted to the specific building categories. If the discount rate were also permitted to vary by building type (as discussed in 5 a. above), this could be used to represent differences or changes in consumer evaluation of future savings or in consumer capability to undertake conservation measures in the specified building types.

Areas where this additional disaggregation could assist policy analysis are suggested below.

(1) Renter-Landlord and Metered Versus Unmetered Status of Building Occupants. In both commercial and residential units the incentives for the occupant to undertake conservation measures differ depending on who benefits from the investments. Ownership offers the advantage of possession of many of the capital purchases; but direct fuel savings accrue by billpaying status. Data to provide BECOM specification and conservation behavior for building types by ownership and billing category are available from several sources:

(a) Owner-Renter Status. For the residential sector, data on fuel use by building and ownership status on initial technology configurations and conservation measures can be found in the Annual Housing Survey and the recently available National Interim Energy Consumption Survey (NIECS).* For the commercial sector similar data are available from surveys such as those in the Hittman Associates, Inc., Commercial Buildings Data Base** and from the Nonresidential Buildings Interim Energy Consumption Survey* when available in early 1981.

**For a summary discussion of both the National Interim Energy Consumption Survey and the Nonresidential Buildings Interim Energy Consumption Survey, see Hittman Associates, Inc., Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D, June 1980.*

***Hittman Associates, Inc., has collected extensive data on commercial sector buildings; see particularly the Commercial Buildings Survey for the California Energy Commission as discussed in Chapter III, Section D.8 of this report.*

(b) Master Metering Status. For the residential sector, data on energy use and conservation measures are available from NIECS; for the commercial sector sources include Hittman's commercial buildings data and the forthcoming Nonresidential Buildings Interim Energy Consumption Survey.

(2) Disaggregation by Income Group. The impact of buildings energy conservation incentives on low-income households can be explored with BECOM by separating the housing types by income levels. Data from the Annual Housing Survey, NIECS, and the Washington Center for Metropolitan Studies Survey can provide information on these distributions by housing type and income. The results of the MATH/CHRDS microanalytic model and the MATH/CHRDS-developed End Use Consumption Data Base (ECDB) for the household sector provide additional distributional and functional end use detail.* If the existing reference or prototypical housing types can be assumed appropriate for the analysis, then inital technology levels for each housing type/income class should also specify their conservation potential. Projections of housing starts and fuel and appliance mix could follow MATH/CHRDS projection assumptions.

Differences in implicit discount rates across income groups have been empirically observed.** Although additional research is required, these rates could be used to suggest income-related differences in time preferences and market imperfections that affect conservation responses. Changes in conservation information and assistance programs and credit market terms by income class could then diffentially affect these discount rates and influence investment decisions toward more energy-efficient choices.

(3) Federal, State and Local Building Energy Analysis. BECOM does not differentiate between building uses in its current specification. However, investment programs to reduce energy use in public buildings could be analyzed by disaggregating existing

**The MATH/CHRDS model is discussed in Chapter II of this report. Both MATH/CHRDS and the ECDB are surveyed in Hittman Associates, Inc., Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D, June 1980.*

***In Hausman, J.A., "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," Bell Journal of Economics, Vol. 8, No. 2, Fall 1979. Income-related discount rates were estimated to vary from 54 percent for low-income households to 9 percent for those with high incomes.*

categories into their federal and state/local fractions. Both federal and state/local buildings are spread among several of the existing BECOM reference commercial sector building types. Jack Faucett Associates has made estimates of energy use by regions for each of these public sector structures.* Office buildings, hospitals, and educational buildings appear to be the key energy users. A variety of special state studies, building stock estimates, and commercial buildings energy surveys, including the Nonresidential Buildings Interim Energy Consumption Survey also provide separate state/local government buildings energy use data. Energy audits and inventories of federal buildings under the Federal Energy Management Program may eventually provide similar data for federal buildings use.

Since the data for both federal and state/local buildings are still relatively weak and because the buildings for these sectors are not clearly differentiated from those of the private sector, any BECOM analysis of these could safely assume the initial energy use characteristics and technologies for the government buildings to be the same as the average for each building type. The federal and state/local fractions in each of the original BECOM building categories (estimated by floor space or by total energy use), could define the new categories. BECOM could then be used, for example, to investigate fuel use impacts and investment levels to meet federal efficiency targets from FEMP, or to calculate cost-effective technologies, investments, and resulting fuel savings that would occur with grants to schools, hospitals, or other public or institutional structures.

c. Indirect Impacts and Linkages to Other Models. BECOM is itself constrained by fixed supplies of fuels to the buildings sector and fixed final buildings energy demands. The model, however, has the capacity to be linked to other models with different specifications and objectives that can extend the policy implications of BECOM analysis beyond the buildings energy use sector. Two of these extensions are listed below.

(1) Interface of BECOM with the Rest of the Energy Sector. BECOM can be run simultaneously with BESOM, the Brookhaven Energy System Optimizaton Model. BESOM offers a detailed representation of the energy

Jack Faucett Associates, Inc. Energy Consumption in Commercial Industries by Census Division - 1974, Federal Energy Administration, 1977. See also Hittman Associates, Inc., op. cit.

supply system and a more aggregated description of final energy demands. The BESOM solution of optimal energy flows from the fixed energy resources to meet the final energy demand yields the levels of fuel supplies available to the residential and commercial buildings sectors. Given these supplies, BECOM derives the more disaggregated energy flows within the buildings sectors. When the two models are run simultaneously, only the final buildings energy demands of BECOM are fixed -- the fuel supplies to the buildings sectors can vary to meet the final demands at least cost, given the energy prices, the availability of energy resources and the technological constraints of the entire energy system. With this model linkage, implications of policies, of exogenous changes in the availability or prices of energy resources, or of advances in energy supply technologies can be investigated as these affect choice of buildings sector technologies and fuels use.

(2) <u>Interface of BECOM's Buildings Energy Sector with the Rest of the Economy</u>. BECOM contains no direct interaction with the economy outside the buildings energy use sector. The model does not attempt to simulate responses of the economy to changes in the buildings sector energy flows nor to changes in buildings energy supplies and demands due to macroeconomic variables. However, it is possible for BECOM to be coupled hierarchically with other energy-economy models. Several options are available:

(a) Aggregate energy-economic models are available whose analyses project final energy demands and energy prices.* Macroeconomic and energy policies can then be linked to growth trends in residential and commercial demands and to changes in energy prices. BECOM analyses would then relate these prices and fuel demands to the optimal technology investment and fuels use in the buildings sector.

**The BNL/Dale Jorgenson model is an example of a long-term energy/economic model whose projection includes estimates of economic quantities and growth, and physical flows of energy, including fuel mix, to final demands. The model is itself an econometric model of interindustry transactions for production and consumption of energy and nonenergy products combined with the BESOM structure to allocate energy supplies to energy demands. This is described in Hoffman, K., and D.W. Jorgenson, "Economic and Technological Models for Evaluation of Energy Policy," <u>Bell Journal of Economics</u>, Vol. 8, No. 2, Fall 1977.*

(b) The impact on the rest of the economy of shifts in building sector energy technologies and fuels uses can be modeled by linking BECOM results to an input-output structure of the energy and economic system as a whole. Buildings energy conservation policies in BECOM affect efficiencies of buildings technologies and the composition of final demands for fuels and buildings conservation investments. These buildings-sector-derived efficiencies and final demands can be translated with the input-output structure into direct and indirect requirements for other goods and services in the economy.*

d. Shadow Prices. There are two major outputs of a linear programming framework such as that used in BECOM. The first major output is the set of intermediate energy flows. In BECOM these are the optimum (least cost) energy flows from given fuel supplies to the final demand, categories as determined by the choice of energy technologies. Almost all analysis with BECOM model focuses on these first outputs.

The second principal output of the linear programming model is the dual variables or "shadow prices" associated with the constraints of the model. These shadow prices give the opportunity cost (or change in the minimum cost solution) for a decrease in the amount each fuel supply constraint or for an increase in each final energy services demand requirement, or for changes in the technological constraints.

Generally, major changes in the level of fuels available to the buildings sector or changes in final demands for energy services from the buildings are not significant policy variables, so that the shadow price analysis capacity of BECOM is infrequently used. If, however, a question were raised of the effect of a major cutback in a supply (for example, No. 2 fuel oil to commercial buildings), then the

**An input-output (I/O) model has been developed at the University of Illinois which is linked to BESOM. The models run iteratively until the inputs for BESOM calculated by the I/O model agree with the inputs for I/O model calculated by BESOM. The results of this combined model are available to translate BECOM efficiencies and energy flows into requirements for goods and services in the rest of the economy. See Carhart, et al., "Energy Employment and Environmental Impacts of Accelerated Investments in Conservation and Solar Technologies in Buildings" for further description of this structure.*

shadow price for loss of that oil could be used to indicate the increased system cost of such an action to the buildings sector. The shadow prices would be equivalent to the least-cost alternatives of technologies and related energy flows which would continue to meet fixed final demands.

From a market point of view, the shadow price of a fuel supplied to the buildings sector is indicative of the market value of that fuel according to the cost the building sector would have to pay if it were to use less fuel, and still meet the required demands. Similar interpretation of demand constraint shadow prices would follow for changes in final energy service requirements for buildings which might occur, for example, if there were major operational conservation cutbacks necessitated by national interests.

c. Data and Parameter Updates. For BECOM to be most useful for policy analysis, the model must represent up-to-date estimates of energy performance and costs, building and equipment stocks, and fuel use. Specifically, as outlined in Section B.3.c., BECOM requires information on (1) current and future building stocks and their fuel market shares; (2) shell and conversion device efficiencies expected for new and existing buildings; (3) the new and retrofit costs for investments in conversion devices and shell efficiency improvements; and (4) the building loads required for each end use (space heating, air conditioning, hot water, lighting, and other appliances) as these vary across climatic regions and building types.

These data are currently provided to the model using 1975 as a base year and drawing heavily on Arthur D. Little, Inc., data on buildings energy use. The five years since 1975 have seen significant changes in buildings energy conservation, both as new and retrofit technologies were adopted and as occupants undertook changes in energy behavior. The 1975 base year makes BECOM useful in determining the policy implications of what "could have been done" if a least-cost energy conservation strategy were followed.* But more up-to-date base year information increases the relevance of the model for current policy analysis, since it is that year's technologies and costs against which the model determines actual projected levels of future investment and technology levels.

A BECOM update to 1977 is being undertaken jointly with Oak Ridge National Laboratories. In particular, this is

This is the course followed in The Least Cost Energy Strategy, Technical Appendix by Carhart et al., 1979.

to include data on levels of energy use, fuel market shares, building and appliance stocks, the structural and conversion technology levels, and the distribution of these across building types and regions of the country. When this is complete this should also bring BECOM into step with the base year of the ORNL residential and commercial energy models, providing comparable base years and data inputs for policy comparisons of the ORNL demand forecast models with the BECOM optimized results. In addition to the base year information, ORNL model forecasts of building and appliance stocks and fuel mix can provide important inputs to BECOM scenarios and ORNL price and income elasticities which could help set price- and income-responsive final demand scenarios for BECOM projections. Provision for such inputs and for regular updates in step with those for the ORNL models would directly facilitate use of BECOM's least-cost analysis in a role parallel but in contrast to that of the ORNL energy demand models for energy policy analyses and forecasting.

f. Multiperiod Analysis.* BECOM provides analysis for only one year or time period at a time. Multiperiod analysis requires multiple runs of the model, with respecification and rerunning of the model for each later period's technologies, new and existing building stocks, efficiencies, etc. In a sense this respecification permits a wider degree of flexibility of model use. The BECOM analyst can vary each new period input and can calibrate the model to other projection results or to new conditions or technologies not expected within the initial period. But this does not offer other users a systematic approach to the procedures and problems of time-stepped analysis. Work is currently being conducted at BNL to develop a more standardized time-stepped version. Several issues are involved:

(1) Consumer Knowledge or Expectations of Future Prices and Technologies. Both a single-period and multiperiod optimization must deal with the question of how to factor in consumer anticipation of future events. But in BECOM's multiple period analysis, any change in this information must come at discrete intervals, so that a conservation investment decided in terms of one period's information may need to be retrofit in the next period due to a changed set of fuel prices or the introduction of more efficient or lower-priced technologies. There is no easy solution to this without completely restructuring BECOM from a single-period model to an n-period linear programming formulation which transfers capacity across time periods, insures smooth transitions, and represents time lags in decisions and investments.**

**This section benefits from conversation with Peter Kleenan of BNL.*

***The Dynamic Energy System Optimization Model, EPRI EA1079, May 1979, is such an n-period linear programming extension for the BESOM model.*

However, a fixed set of procedures and additional discussion of how these problems have been or will be handled in multiple-period BECOM analysis would considerably enhance evaluation of the results and assist future studies by analysts other than BNL staff.

(2) Model Accounting for Housing and Appliance Vintages. In principle, over a number of BECOM optimization periods there would be a increasing number of building and appliance types distinguished by the technologies they embody and the time period in which they were purchased (e.g., existing pre-1975 homes; "new" 1975-to-1980 homes, retrofit existing homes, new 1980-to-1985 homes, etc.). These in turn vary by region. In practice this problem is lessened both because the model does not contain vintaged housing or appliances (see subsection h below) and because each new time period operates with only the existing (pre-1975) and post-1975 prototypical building types at various efficiency levels selected in the previous period. However, this pre- and post-1975 distinction becomes somewhat artifical by, say, 1990. For multiple-period analysis it might be easier to reduce the number of different building types and have all the adjustment in changed efficiency levels. This is in fact being considered by BNL.*

g. Model Transferability and Accessibility. BECOM can be a valuable and versatile tool for building energy conservation analysis. Once studied, the model structure is seen to be a basically straightforward application of linear programming analyis and the policy applications easily visualized. But in its present accessibility and documentation, its use and thorough understanding are limited for the most part to BNL staff and those associated with its development. For model use and applications to grow and for its value for policy analysis to be better realized, others outside of BNL staff and its authors need to be involved in its use. The model is not currently on any other computer installation. Though it can be accessed by remote terminal, at present both altering the model and making a run are sufficiently complex to impede widespread use or understanding. Several steps should be considered to encourage the model's broader use.

(1) Transferability. A major effort needs to be undertaken to make BECOM transferable to other institutions, including EIA and other parts of DOE. BECOM is currently implemented at BNL using CDC's APEX III linear programming package and the PDS/MaGen which puts the data in the correct order for APEX III. Since the model is also

Based on conversations with Peter Kleenan of BNL.

programmed in the languages of this APEX MaGen system, it could easily be transferred to other CDC installations, but not so easily to other computers. However, with additional effort by BNL and/or CDC staff (and proper funding) the transfer to IBM could take advantage of a certain amount of compatibility with IBM equipment. The input to APEX III is the same as that to IBM's MPS system.

(2) Documentation. The general model structure is well documented in Carhart, Mulherkar and Sanborn, The Brookhaven Buildings Energy Conservation Optimization Model. This report, however, lacks specific detail on how the model actually runs and how to use it. For BECOM to be better understood and used, a users' manual should be developed giving detailed flow diagrams, step-by-step explanation of the model setup and runs, sample runs, and a carefully documented description of the data inputs and actual data that have been used. This would also greatly enhance access to the model via remote terminal to the BNL computer.

(3) Standardization. At the cost of some flexibility of model use, additional standardization of the model procedures for operational runs would also enhance its use by others. Two areas have been mentioned earlier:

(a) Multiple-period analysis and the need for formalized procedures to time-step the analysis

(b) Reduction in the number of building types so that regional, age, and time period differences are reflected to a greater extent by their technologies and service levels and less by a large number of building types.

h. Additional Areas - Building and Appliance Age, Retirements, and Salvage Values.

(1) Retirements. BECOM assumes that buildings and appliances have fixed lifetimes and that a percentage of each given type is physically retired from the system each year in inverse proportion to their lifetimes. The reason for this is that there is basically no vintage or age specification on building types or appliances except for the category "pre-1975" buildings in the current version. This is a necessary simplification to ease the model accounting, which even in its current version considers over 6,000 variables.

So long as building and appliance types are purchased at a fairly uniform rate, this retirement procedure will create little problem. However, at any point where there are large numbers of new purchases, discrepancies can occur. Actual retirements are more likely to follow a logistic curve, with few retirements in the early years but increasing rapidly after that to yield the average lifetime.* As long as the stock is uniformly distributed with age, the number of retirements will "average out." However, when a large number are purchased at one time, the present formulation will show too many retired in the early years and too few later.

Without complicating the model with building and appliance vintages, this potential problem area would be difficult to correct. Exogenous projection of retirements from more disaggregated housing models could assist, but since serious error would only occur with very "lumpy" investments, perhaps the simplest solution is simply to be observant of these occurrences.

(2) Salvage Values in Retrofit of Appliances. BECOM assumes that once an equipment purchase has occurred, its value is considered as sunk costs -- only variable operating and fuel costs enter future evaluation criteria. In reality, if the equipment is not near the end of its physical lifetime, it may have salvage value if retired. By not considering this salvage value the model somewhat underestimates the number of retrofits. Correction for this may be impractical considering the amount of data required (salvage values for each appliance by year of purchase and age) and the fact that the model does not track either. For some categories, such as refrigerators or washers and dryers, some correction could be included.

D. Bibliography

Arthur D. Little, Inc. Project Independence: Residential and Commercial Energy Use Patterns, 1970-1990. Report to the President's Council on Environmental Quality and the Federal Energy Administration, November 1974.

*For a discussion of this logistic curve for retirements of commercial buildings, see Jackson, et al., 1978, *The Commercial Demand for Energy, A Disaggregated Approach*, ORNL/CON 15, p. 23-24.*

Beller, M., editor. Sourcebook for Energy Assessment, BNL 50483. Brookhaven National Laboratory, December 1975.

Brookhaven National Laboratory. Dynamic Energy System Optimization Model, EPRI EA 1079, May 1979.

Brookhaven National Laboratory. Regional Reference Energy Systems, Topical Report EPRI EA-462. Prepared for the Electric Power Research Institute, June 1977.

Carhart, Steven C., Shirish S. Mulherkar, and Yasuko Sanborn. The Brookhaven Buildings Energy Conservation Optimization Model. Prepared for the Division of Buildings and Community Systems, U.S. Department of Energy, by the Economic Analysis Division, Department of Energy and Environment, Brookhaven National Laboratory, January 1978.

Carhart, S., S. Mulherkar, and J. Schwam. Energy, Employment, and Environmental Impacts of Accelerated Investment in Conservation in Solar Technologies in Buildings, BNL-27805. Brookhaven National Laboratory, October 1978.

Carhart, Steven C., et al. The Least-Cost Energy Strategy -Technical Appendix. Pittsburgh, Pennsylvania: Carnegie-Mellon University Press, 1979.

Cherniavsky, E.A. Brookhaven Energy System Optimization Model, Informal Report, BNL 19569. Brookhaven National Laboratory, 1974.

Cherniavsky, E.A., A.S. Kydes, et al. Brookhaven Energy Systems Optimization Model - Methodology and Documentation (Version 2.1), BNL report, in preparation. Brookhaven National Laboratory.

Cohn, S. Fuel Choice and Aggregate Energy Demand in the Commercial Sector, ORNL/CON-27. Oak Ridge National Laboratory, December 1978.

Cohn, S., E. Hirst, and J. Jackson. Econometric Analysis of Household Fuel Demand, ORNL/CON 7. Oak Ridge National Laboratory, March 1977.

Daifuku, R. Residential Sapce Heating and Cooling in New England 1972-200, BNL 50614. Brookhaven National Laboratory, December 1976.

Fraser, J.T., Documentation of the Brookhaven Energy I-0 and I-0/BESOM Linkage, BNL 50856, Upton, NY, 1978.

Glesk, M. Potential for Energy Technologies in Residential and Commercial Buildings, DOE/PE/03781-T1. Arthur D. Little, Inc., November 1979.

Glesk, M. Residential/Commercial Market for Energy Technologies, DOE/AD/03871-T2. Arthur D. Little, Inc., August 1979.

Goldberg, M.D. An Energy Model Data Base, Informal Report, BNL 19200. Brookhaven National Laboratory, undated (1973).

Hausman, J.A. "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables." Bell Journal of Economics, (Spring 1979), pp. 33-54.

Hoffman, K., and D. Jorgenson. "Economic and Technological Models for Evaluation of Energy Policy." Bell Journal of Economics, Vol. 8, No. 2 (Fall 1979).

Hirst, E., and J. Carney. The ORNL Engineering-Economic Model of Residential Energy Use, ORNL/CON-24. Oak Ridge National Laboratory, July 1978.

Hittman Associates, Inc. Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, HCI011/002-80-931D2. June 1980.

Hittman Associates, Inc. "Nonresidential Buildings Surveys of Energy Consumption," Section I. Major Models and Data Sources for Residential and Commercial Sector Energy Conservation Analysis, H931D (Draft). June 1980.

Jack Faucett Associates, Inc. Energy Consumption in Commercial Industries by Census Division - 1974. Chevy Chase, Maryland, March 1977.

Jackson, J.R., et al. The Commercial Demand for Energy: A Disaggregated Approach, ORNL/CON-15. Oak Ridge National Laboraory, April 1978.

Lin, W., E. Hirst, and S. Cohn. Fuel Choices in the Household Sector, ORNL/CON-3. Oak Ridge National Laboratory, October 1976.

Marcuse, W., S. Carhart, and S. Mulherkar. "Residential Energy Demand Analysis - Data and Methodology," BNL 21920. Presented at Joint National Meeting Operations Res. Soc. Am. and Institute of Management Science, Miami, November 1976.

O'Neal, D., K. Corum, and J. Jones. "An Estimate of Consumer Discount Rate Implicit in Single-Family Housing Construction Practices," Working Paper. Oak Ridge National Laboratory, June 1980.

Sant, Roger. The Least Cost Energy Strategy Minimizing Consumer Costs Through Completion. The Energy Productivity Center, Mellon Institute, 1979.

U.S. Department of Commerce, Bureau of the Census. Annual Housing Survey: 1977 Current Housing Reports, United States and Rgions, H150-77-(AE). U.S. Government Printing Office, 1979.

U.S. Department of Energy. Energy Efficiency Standards for Consumer Products - Economic Analysis. Technical Support Document No. 4, DOE/CS-0169. June 1980.

U.S. Department of Energy. Energy Efficiency Standards for Consumer Products - Engineering Analysis. Technical Support Document No. 5, DOE/CS-0166. June 1980.

U.S. Department of Enegy, Energy Information Administraton. "Residential Energy Consumption Survey: Characteristics of the Housing Stock and Households, 1978," DOE/EIA-607/2. February 1980.

U.S. Department of Energy, Energy Information Adminstration. "Residential Energy Consumption Survey: Conservation," DOE/EIA-0207/3. February 1980.

U.S. Department of Housing and Urban Development, and U.S. Department of Energy. Phase One/Base Data for the Development of Energy Performance Standards for New Buildings, Final Report. Prepared by AIA Research Corporation under Contract No. H-2689, January 1978.

U.S. Department of Housing and Urban Development, and U.S. Department of Energy. Phase Two Report for the Development of Energy Performance Standards for New Buildings, Task Report, Appendix D: Descriptions and Drawings: 168 redesigns. Prepared by AIA Research Corporation, Washington, DC, January 1979.

U.S. Department of Housing and Urban Development, and U.S. Department of Energy. Phase Two Report for the Development of Energy Performance Standards for New Buildings, Task Report: Commercial and Multifamily Residential Buildings. Prepared by AIA Research Corporation, Washington, DC, January 1979.

U.S. Department of Housing and Urban Development, and U.S. Department of Energy. Phase Two Report of Energy Performance Standards for New Buildings: Final Report. Prepared by AIA Research Corporation, Washington, DC, January 1979.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX A

GOALS AND OBJECTIVES OF DOE IN BUILDINGS ENERGY CONSERVATION

A necessary step in assessing the ability of selected models to provide information that will be useful to the Buildings Section of the Conservation Policy Office is postulation of DOE's goals and objectives in the buildings energy conservation area. These goals and objectives will suggest the types of analyses, data inputs, and model outputs needed to evaluate specific initiatives targeted on buildings energy conservation problems. When the types of analyses, data inputs, and model outputs needed are identified, the models and data bases selected can be analyzed to assess their ability to provide the required output.

DOE's goals and objectives in the residential and commercial sector were identified through a careful review of several strategy and program planning documents in the buildings energy conservation sector and through discussions with the Buildings Section of the Conservation Policy Office. It was apparent immediately that there are numerous types and levels of government ends and means in the buildings conservation area. Therefore, to bring order to the search for goals and objectives, a taxonomy was created that provided a structure into which the numerous goals and objectives could be categorized. This structure was used to identify the kinds of objectives that were most relevant to the immediate objective: to identify the types of analyses, data inputs, and model outputs needed to evaluate specific initiatives targeted in buildings energy conservation.

The taxonomy was based on the assumption that policy makers start with very general goals which they accept as their ultimate mission and then identify a series of derivative objectives and policies -- each more specific than those preceding it -- by which they intend to achieve their general goals. Eventually, they will have identified specific steps that can be taken in pursuit of their goals.

To put this taxonomy into operation, very general goals were abstracted from the planning documents. An example of such a general goal is improvement of the efficiency of energy usage in buildings. Next, their general objectives or situations which, if achieved, would help to satisfy the general goals were sought. As an example, DOE policy makers have set as a target improvement of the efficiency of energy use in existing residential buildings. This became a general objective aimed at satisfying the goal to improve the efficiency of energy usage in buildings in general. Policies or general types of action that should be taken with the general objectives in view were next sought. An example of such a policy is acceleration of the introduction of buildings-related energy-conserving technologies into the marketplace. Next in the sequence are specific objectives or more narrowly defined situations suggested by policy, which, if realized, would help to achieve the general objectives. An example of a specific objective is the retrofit of existing residential buildings with specific energy-conserving/energy-efficient technologies.

Finally, the commitments or programs that are created to implement specific actions designed to achieve the specific objectives were identified. The Residential Conservation Service Program is an example of such a commitment of resources aimed at satisfying all of the preceding objectives and policies.

The results of this analysis of goals and objectives and their categorization are presented in Tables A-1 and A-2. To repeat, the purpose of these tables is simply to structure the numerous goals, objectives, and policies encountered in order to facilitate the identification of those that seem most relevant to the problem of identifying the model output and data input requirements of the Buildings Section.

Table A-1 presents DOE's stated goals, general objectives, and policies aimed at satisfying DOE's mission in the buildings energy conservation sector.

Table A-2 presents the specific objectives and programs designed to achieve the general objectives within the policy constraints. Table A-2 also lists several topical questions which are seen by the Buildings Section as issues with which they may have to deal in the near future. The model outputs and data needed to respond to the topical questions will be similar to those needed for several of the specified objectives; therefore, although the questions appear in a separate column, they are intended to be on the same level as the specific objectives to which they are related. Except where noted, each objective is understood to exist for near-, mid-, and long-term time frames.

The specific objectives and topical questions are the points in the taxonomical scheme where the goals and objectives are thought to be specific enough to permit identification of the model output and data input requirements to begin. As a result, the categorization was stopped here. The model output and data input needs identified were those either necessary to assess the policy initiatives producing or program initiatives targeted on the specific objectives or those necessary to answer the topical questions.

In Table A-2, the specific objectives are grouped into numbered subcategories (for example, "Commercial Buildings Sector Objectives"). The topical questions are also numbered. Since some of the questions are relevant to several specific objectives, they may appear adjacent to more than one subcategory of objectives. Each time a particular topical question appears, however, it will have the same number. For example, the topical question, "What is the impact on oil and gas usage?" is relevant to many of DOE's specific objectives in the buildings sector and, therefore, appears several times in Table A-2, but always with the number 1.

The numbering of the categories of specific objectives and the topical questions indicates the relative importance of that category/question for the Buildings Section's near-term (18 months) analytic needs. This priority ranking was established after discussion of the lists with members of the Buildings Section of the Conservation Policy Office. This priority ranking was used to indicate the objectives and questions whose model outputs and data needs should be examined first. Where a high-priority topical question is paired with a lower-priority specific objective, those model output and data input requirements associated with the specific objective needed to answer the question were examined using the topical question's priority rather than the specific objective's priority. Other analytic requirements of the lower-priority specific objective were then examined in turn.

TABLE A-1. ENERGY CONSERVATION GOALS AND OBJECTIVES IN THE BUILDINGS SECTOR

DOE Energy & Non-Energy Goals in the Residential/Commercial Sector	DOE General Objectives to Achieve Energy Goals	DOE General Objectives to Achieve Non-Energy Goals	DOE Policy to Achieve General Objectives
Improvement of efficiency of energy usage in residential and commercial buildings	Improvement of energy efficiency in existing residential buildings	Overall national benefit exceeds overall national costs	Accelerate introduction of buildings-related energy-conserving technologies into market place
Reduction in total energy usage	Improvement of energy efficiency in new residential buildings	Overall national benefit substantially exceeds government costs	Motivate customers to alter energy use patterns
Reduction in dependence on foreign oil	Improvement of energy efficiency in existing commercial buildings	Overall distribution of costs and benefits is equitable	Identify and ease barriers to technology and pattern change
Reduction in dependence on oil and gas in general as energy sources	Improvement of energy efficiency in new commercial buildings	Interference with free market is minimized	Encourage involvement of state and local governments as much as possible in energy management activities
Minimization of impact on life style	Improvement of energy efficiency in appliances and products used in each building type	Local benefits and participation are maximized	Programs should be site-specific to the greatest extent possible
	Reduction in oil usage	Improvement in national employment	Programs should try to make maximum use of market forces
	Reduction in gas usage		R&D projects should be high-risk with high payoff
	Energy prices increased to their replacement price, then stabilized		Substitute renewable resources for non-renewable resources
	Improvement of energy efficiency in systems that supply energy to buildings		Deregulate energy prices
			Programs should complement other energy-saving programs
			Programs should complement environmental objectives
			Avoid programs aimed at outcomes that will happen just as fast without government intervention

TABLE A-2. SPECIFIC OBJECTIVES FOR WHICH PROGRAM COMMITMENTS HAVE BEEN MADE OR COULD BE PROPOSED AND TOPICAL QUESTIONS

Specific Objective	Program*	Topical Questions
1. Commercial Buildings Sector Objectives		1. What is the impact on oil and gas usage?
Retrofit of existing commercial buildings with selected energy-conserving/energy-efficient technologies.	Energy Tax Credit Energy Conservation Bank Vendors rebate on energy-efficient matching program	2. Are sufficient production capacities and material resources available to meet the increased demand for retrofit materials without causing price increases above the otherwise-expected rate of inflation?
See new commercial buildings constructed with a minimum standard of improved energy performance.	Buildings Energy Performance Standards	3. Are there regional differences in attitudes towards retrofitting with improved energy-efficiency technologies?
2. Residential Buildings Sector Objectives		1. What is the impact on oil and gas usage?
Retrofit of existing residential buildings with selected energy-conserving/energy-efficient technologies	Residential Conservation Service Energy Tax Credits Energy Conservation Bank Vendor rebate on energy-efficient matching program	2. Are sufficient production capacities and material resources available to meet the increased demand for retrofit materials without causing price increases above the otherwise-expected rate of inflation?
	Free energy audits by utilities Time-of-transfer energy audit	3. Are there regional differences in attitudes toward retrofitting with improved energy-efficiency technologies?

**The list of programs is indicative. Every program currently sponsored by DOE or proposed to achieve specific objectives has not been included.*

TABLE A-2. (CONTINUED)

Specific Objective	Program*	Topical Questions
All new residential buildings constructed with a minimum standard of improved energy performance	Buildings Energy Performance Standards	
Retrofit of tenant-occupied residential buildings	Energy Tax Credits Time-of-transfer energy audit	
Retrofit of existing residential buildings heated with No. 2 fuel oil	Fuel Oil Marketing Demonstration Program	
Retrofit of existing and residential buildings owned and occupied by low-income households. Specifically, weatherization of 2.7 million homes by 1985.	Weatherization Assistance	
3. State and Local Building Objectives		1. What is the impact on oil and gas usage?
Retrofit of state and local government and institutional buildings. Specifically, retrofit of 42,000 institutional buildings by 1983.	Institutional Buildings Grant Program	2. Are sufficient production capacities and material resources available to meet the increased demand for retrofit materials without causing price increases above the otherwise expected rate of inflation? 3. Are there regional differences in attitudes toward retrofitting with improved energy-efficiency technologies?

The list of programs is indicative. Every program currently sponsored by DOE or proposed to achieve specific objectives has not been included.

TABLE A-2. (CONTINUED)

Specific Objective	Program*	Topical Questions
4. Utility Conservation Action Objectives		4a. Who is interested in or capable of promoting energy conservation activity besides the U.S. Government. Specifically, what are the capabilities of utilities? 4b. What actions are PUCs and utilities taking that affect energy conservation?
5. Other Energy Source RD&D Objectives		1. What will the impact be on oil and gas usage?
Demonstrated feasibility of renewable resources technologies.	Appropriate Technology Small Grants	2. What analytic requirements are needed to assess the emerging use of wood, solar energy, and geothermal resources to heat houses?
6. Federal Buildings Objectives		1. What is the impact on oil and gas usage?
Reduction of energy usage in existing Federal Buildings by 20 percent by 1985. Reduction of energy usage in new Federal Buildings by 45 percent by 1985.	Federal Energy Management Program	2. Are sufficient production capacities and material resources available to meet the increased demand for retrofit materials without causing price increases above the otherwise expected rate of inflation?

The list of programs is indicative. Every program currently sponsored by DOE or proposed to achieve specific objectives has not been included.

TABLE A-2. (CONTINUED)

Specific Objective	Program*	Topical Questions
7. Consumer Usage Practices Objectives		1. What is the impact on oil and gas usage?
Change in residential consumer energy use practices resulting in reduced use per capita.	Residential Conservation Service Consumer Education Program Fuel Oil Marketing Demonstration Low-Cost/No-Cost Measures Program	3. Are there regional differences in attitudes toward energy usage practices? 6. Do residents and commercial building occupants who retrofit their buildings then increase their comfort level resulting in little or no change in energy usage?
Change in commercial consumer energy use practices resulting in reduced use per square foot	Time-of-Day Utility Rates	
8. Appliance Efficiency Objectives		1. What is the impact on oil and gas usage?
All new major appliances manufactured to meet minimum energy efficiency performance standards.	Appliance Efficiency Standards Test Procedures and Efficiency Targets Program	

The list of programs is indicative. Every program currently sponsored by DOE or proposed to achieve specific objectives has not been included.

TABLE A-2. (CONTINUED)

Specific Objective	Program*	Topical Questions
9. Community Systems Objectives		1. What is the impact on oil and gas usage?
Implementation of community district heating systems using cogeneration.	Tax Credit and accelerated depreciation	2. Are sufficient production capacities and material resources available to meet the increased demand for district heating materials without causing price increases above the otherwise expected rate of inflation?
Creation of technical assistance teams to aid communities in making "front-end" decisions about their energy future.		
States have Comprehensive State Energy Management Plans.	Energy Management Partnership Act	3. Are there regional differences in attitudes toward retrofitting with improved energy-efficiency technologies?
Energy Offices established in localities.	Community Energy Action Grants Program	
Regional technical assistance panels available.	Community Energy Action Grants Program	
Local energy information clearinghouses available.	Energy Extension Service	

**The list of programs is indicative. Every program currently sponsored by DOE or proposed to achieve specific objectives has not been included.*