BNL 50828

DR. 2222

THE BROOKHAVEN BUILDINGS ENERGY CONSERVATION OPTIMIZATION MODEL

Steven C. Carhart, Shirish S. Mulherkar, and Yasuko Sanborn

January 1978

Prepared for the
DIVISION OF BUILDINGS AND COMMUNITY SYSTEMS
UNITED STATES DEPARTMENT OF ENERGY
by the
ECONOMIC ANALYSIS DIVISION
DEPARTMENT OF ENERGY AND ENVIRONMENT

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UNDER CONTRACT NO. EY-76-C-02-0016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY

BNL 50828
UC-95d
(Energy Conservation - Buildings and
Community Systems - TID-4500)

THE BROOKHAVEN BUILDINGS ENERGY CONSERVATION OPTIMIZATION MODEL

Steven C. Carhart, Shirish S. Mulherkar, and Yasuko Sanborn

January 1978

Prepared for the
DIVISION OF BUILDINGS AND COMMUNITY SYSTEMS
UNITED STATES DEPARTMENT OF ENERGY
by the
ECONOMIC ANALYSIS DIVISION
DEPARTMENT OF ENERGY AND ENVIRONMENT

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $6.00; Microfiche $3.00

October 1978 475 copies

ABSTRACT

The Brookhaven Buildings Energy Conservation Optimization Model is a linear programming representation of energy use in buildings. Starting with engineering and economic data on cost and performance of energy technologies used in buildings, including both conversion devices (such as heat pumps) and structural improvements, the model constructs alternative flows for energy through the technologies to meet demands for space heating, air conditioning, thermal applications, and electric lighting and appliances. Alternative paths have different costs and efficiencies. Within constraints such as total demand for energy services, retirement of existing buildings, seasonal operation of certain devices, and others, the model calculates an optimal configuration of energy technologies in buildings.

The penetration of the various basic technologies within this configuration is specified in considerable detail, covering new and retrofit markets for nine building types in four regions. Each market may choose from several appropriate conversion devices and four levels each of new and retrofit structural improvement.

The principal applications for which the model was designed include the following: market penetration anaylsis, showing the role of individual technologies within a system context; policy analysis, to show the effect of buildings sector policies on the technologies in the building stock; analysis of RD&D programs; analysis of the preferred configuration for sensitivity to changes in price or other variables; analysis of the effect of technology implementation rates on overall energy; and the environmental and supply system effects of buildings energy conservation.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONTENTS

1. Introduction

The Brookhaven Buildings Energy Conservation Optimization Model (BECOM) is designed to provide a tool for projecting, analyzing, and evaluating the energy implications of conventional and proposed energy-related technologies in buildings. Starting with detailed cost and performance data for individual building technologies, the model assembles alternative combinations of these technologies within a linear programming framework. For any combination of building stocks, fuel prices and availabilities, and other constraints on technological availability, BECOM calculates the preferred technological configuration of the buildings sector. Because the basic elements of the model are specified in terms of technologies, this configuration is expressed in terms of levels of market penetration of specific technologies. BECOM is designed as an extension of the Brookhaven Energy System Optimization Model (BESOM).

BESOM is a representation of the technological and economic features of the energy system. It has been used for detailed analyses of energy resource allocation and technology implementation.[1] BESOM is a linear programming formulation of the Reference Energy System (RES). The RES, shown in Figure 1, is a specialized format for representing the detailed technological structure of the energy system. Solution of the BESOM model yields resource consumption, energy flows through the RES network, and emissions to air and water. Efficiency, cost, and environmental data are supplied by the Energy Model Data Base.[2,3] Each flow through the network represents a process

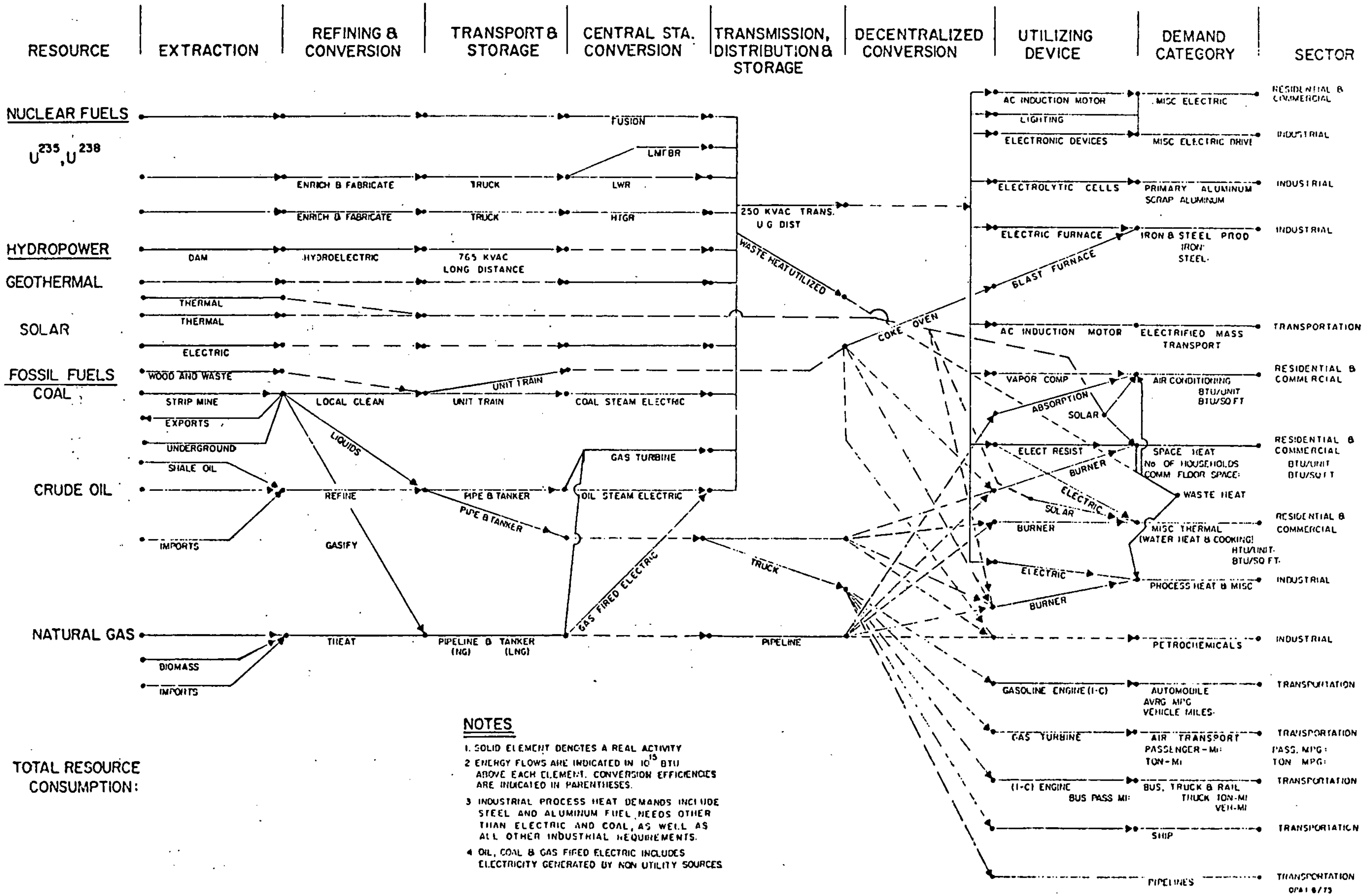


Figure 1. Reference energy system, year.

or mix of processes to convert some primary resource into a fuel to meet some end use. Demand is specified by a specially defined term - the basic energy demand - which is the amount of energy required to support an energy-utilizing activity such as space heat, automotive propulsion, etc., at some nominal level (assuming no changes in equipment operation or user behavior). For a given basic energy demand, all other levels in a particular model run of energy flows are characterized as changes in technical demand efficiency. Basic energy demands are converted to fuel requirements by adjusting for demand conversion efficiencies, and fuel requirements are converted to primary resource demands by adjusting via appropriate supply conversion efficiencies. This generates the fuel mix and the primary resource mix.

Though BESOM contains a detailed representation of the supply system, it has a highly aggregated representation of the demand portion of the system. The methodology for extension of this approach for energy utilization technology has been described elsewhere[4] and is carried out in detail in the Buildings Energy Conservation Optimization Model (BECOM). BECOM extends BESOM to provide more end-use detail for residential and commercial buildings, explicitly modeling 25 energy conversion technologies and 8 structural technologies that can be used by 9 building types in each of 4 regions. The model covers all energy use in buildings including space heat, air conditioning, water heating, cooking, and appliance and illumination loads. As a result it is possible to measure in detail the effects of technical changes in burners, motors, and other conversion devices* and in structural shells as well as the effects of governmental programs such as setting standards for building insulation and appliance efficiency.

BECOM thus allows an explicit and flexible formulation of the policy variables that the decision maker wishes to analyze. For a given set of inputs, the linear programming algorithm implements the lowest-cost technology in a particular market to the maximum level set by constraints. This decision can be made on the basis of very small cost differentials between technologies. Thus, technology implementation levels should be interpreted with care. However, this difficulty inherent in linear programming is mitigated in BECOM by the use of 72 separate building markets, which may be further subdivided by market share constraints.

2. Structure of BECOM

2.1. Mathematical Structure

Mathematically the model is formulated as a modified transportation/transshipment problem. A transportation problem is concerned with distributing a commodity from any group of supply centers (sources) to any group of demand points (destinations), subject to limitations imposed by supply, demand, and other constraints. Each supply point i (i = 1, 2, ...,m)

*To simplify the exposition, the set of end-use energy conversion devices used in buildings by households, government activities, and commercial enterprises will be called conversion devices. This includes burners, heat pumps, electric motors, condensers, light bulbs and other illuminating equipment, blower fans, etc.

has a supply of S_i units to distribute to any destination j (j = 1, 2, ..., n), each of which has a demand for D_j units to be received from the sources. Assuming that the cost of distributing units from source i to destination j is proportional to the number of units shipped, the objective is to meet demands at all destinations at minimum cost.

The problem then becomes

$$\text{Minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$$

where Z is the total distribution cost; C_{ij} is the cost of shipping each unit from source i to destination j; and X_{ij} is the number of units shipped from i to j. Since the total number of units shipped from source i cannot be greater than the supply available, and since the demand at each destination has to be met, the constraints given below are introduced.

Supply constraint:

$$\sum_{j=1}^{n} a_{ij} X_{ij} \leq S_i \qquad \text{for } i = 1, 2, \ldots, m$$

Demand constraint:

$$\sum_{i=1}^{m} b_{ij} X_{ij} = D_j \qquad \text{for } j = 1, 2, \ldots, n$$

Also:

$$X_{ij} \geq 0 \qquad \text{for all i and j.}$$

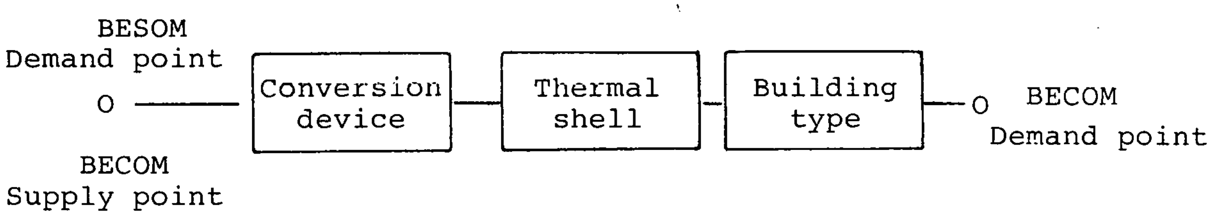
Here, a_{ij} and b_{ij} are the supply and demand efficiencies, respectively, for the fuel X_{ij}.

Besides the supply and demand constraints, there are various equations which reflect technological realities and market behavior. These are treated in more detail in Section 2.3.

BESOM is basically a modified transportation problem where the X_{ij}'s represent the flow of energy (in 10^{15} Btu) from a resource to a demand at point of use. Each branch can be divided into two parts: a supply trajectory describing the conversion of a resource into an intermediate energy form (such as elcctricity or distillate oil delivered to the home) and a demand trajectory including all further processes on the branch. There are now 27 supply and 22 demand categories.

The structure of BECOM is similar to that of a transshipment problem, with the aggregate demand points from BESOM for residential/commercial space heat, air conditioning, water heating, and appliances serving as sources for the transshipment.

The destinations for this problem are the different buildings markets, each of which requires a certain amount of energy to provide an acceptable level of comfort or service. Shipments from sources to destinations are made through intermediate transfer points or transshipment points, which in this case are conversion devices and thermal shells.



Each conversion device is characterized by an efficiency coefficient representing the efficiency of conversion of the fuel in the device and a cost coefficient which is the annualized capital cost for the device. Devices in existing buildings have a cost coefficient of zero since they are already in place. The thermal shell* is similarly characterized by an efficiency coefficient which compares its heat-loss characteristics with those of a defined reference shell, and by a cost coefficient which is the annualized capital cost of upgrading a structure relative to the reference shell. Non-upgraded buildings and reference new buildings have an efficiency of 1. Upgraded shells have higher efficiencies. The energy demand in each market can be met by any combination of firing device and thermal shell (represented schematically in Figures 2 to 7).

If the model is run as a cost minimization, it selects those combinations of conversion devices and thermal integrities that will satisfy demands in the various markets subject to the limitations imposed by the other constraints.

The operation of the model may be illustrated by following one example in the diagram for residential space heat. In the "fuel" column in Figure 2 all the BESOM gas to space heat variables are gathered in a pool to serve as the gas source for heating residential and commercial buildings. The gas or other fuel goes to two demand points: the detailed flow network representing technologies in buildings in one particular region, and an aggregated demand representing demand in the other three

*The shell is a level of energy integrity. For space heating and air conditiong, the shell corresponds to the building envelope; for water heating it can be interpreted to be the pipe and heater insulation; and for the appliance sector it is a representation of performance of improved appliance package.

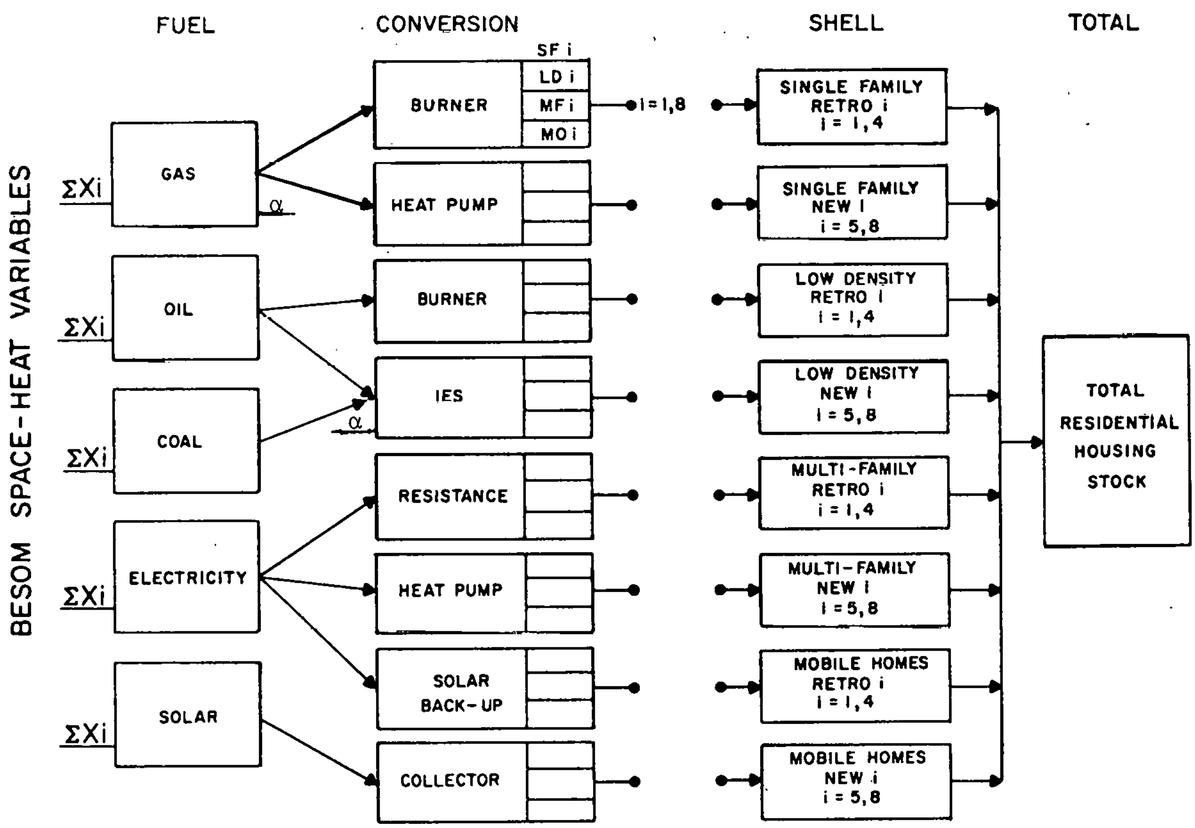


Figure 2. BECOM: Structure of residential space heat.

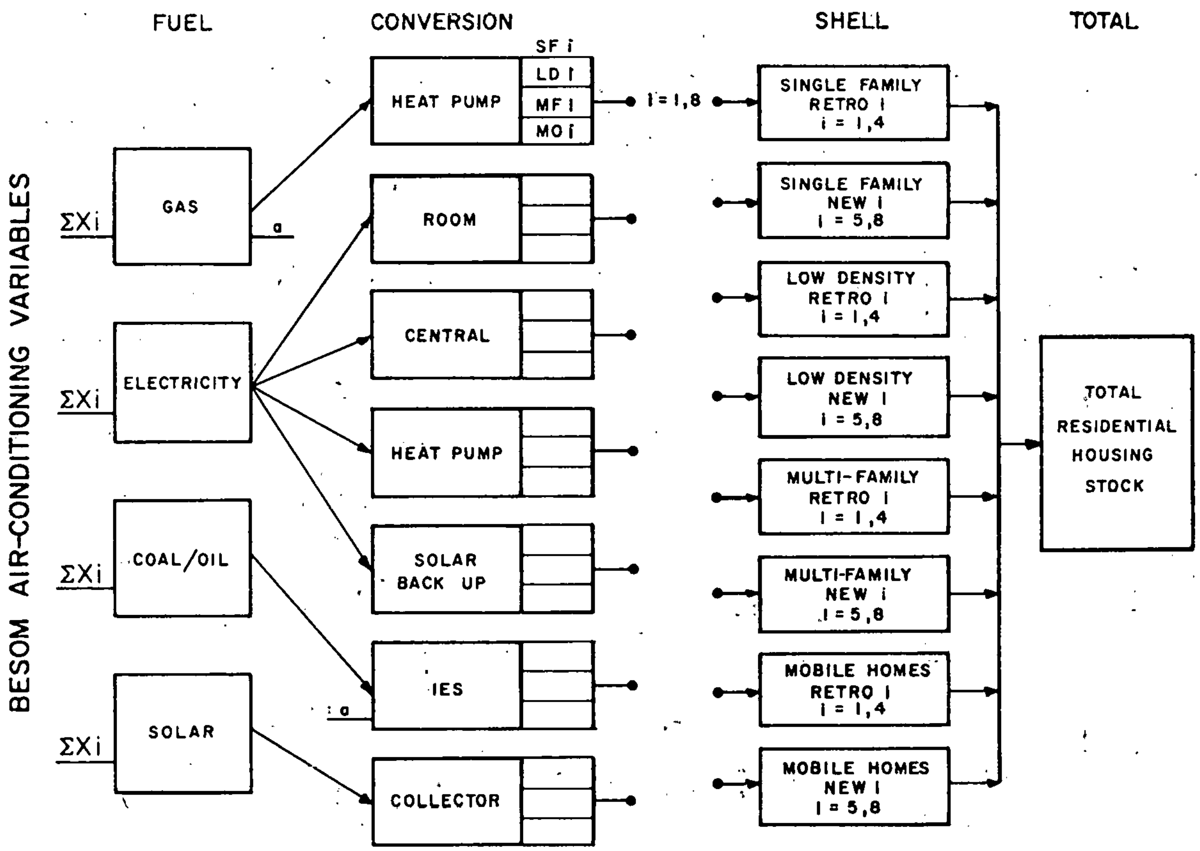


Figure 3. BECOM: Structure of residential air conditioning.

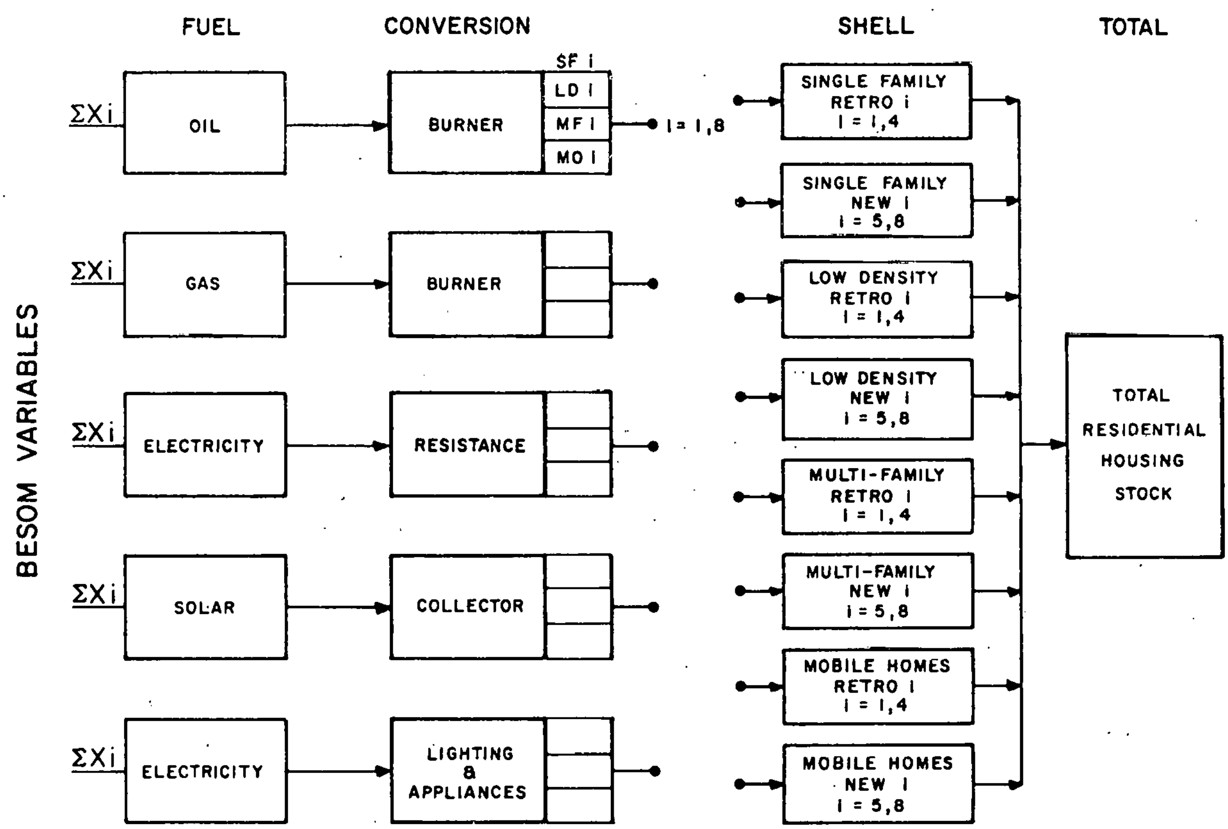


Figure 4. Structure of residential thermal, lighting and appliances.

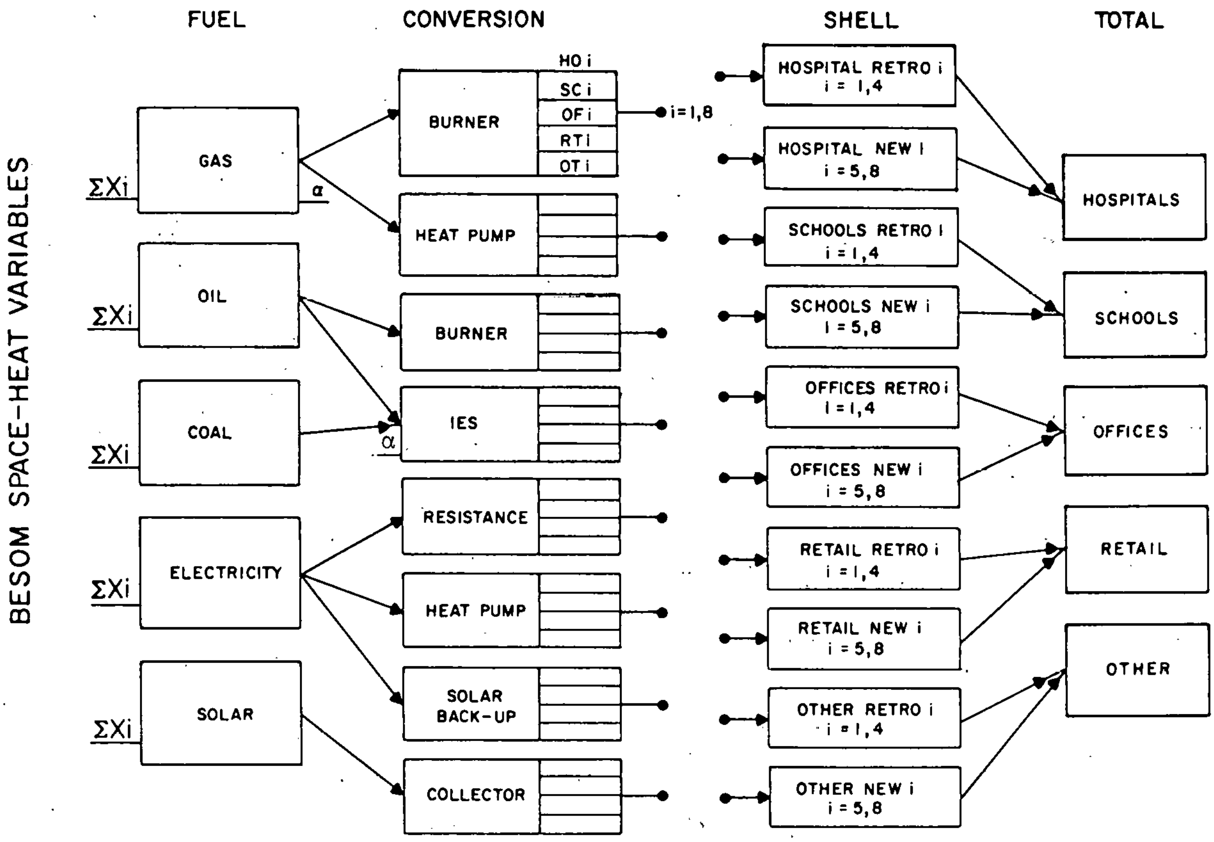


Figure 5. BECOM: Structure of commercial space heat.

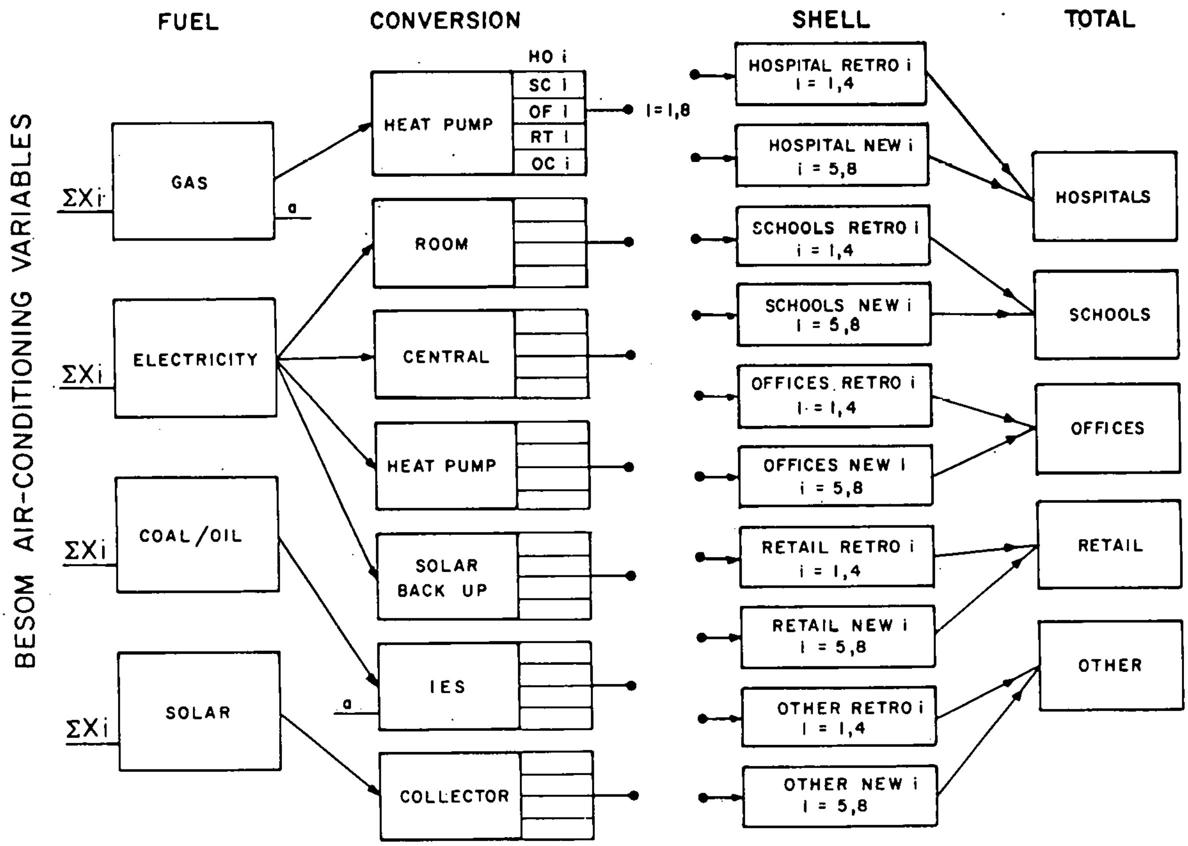


Figure 6. BECOM: Structure of commercial air conditioning.

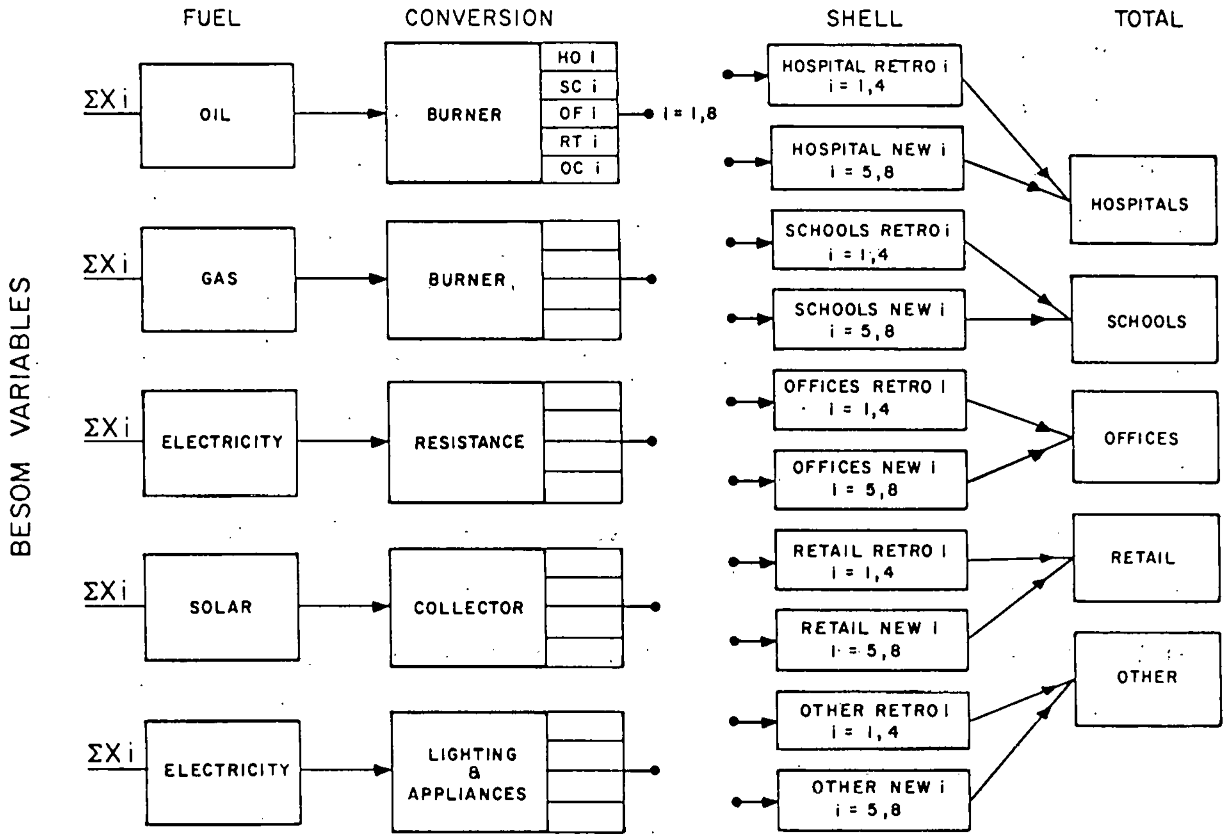


Figure 7. Structure of BECOM commercial thermal, lighting and appliances.

regions. The output thus represents national energy flows to the buildings sector, with technological detail presented in one region at a time. The model is run successively with each region represented in detail in turn to develop a full national projection.

The detailed regional flows go as follows. Each unit of the new variable representing the total gas to residential space heat can flow either to a gas heat pump or to a gas burner. If it flows to a burner, upon coming out of the burner it is multiplied by the energy-conversion efficiency of the burner and incurs a cost equal to the annualized capital cost of the burner if it is a new burner, or a zero cost if it is an old burner. If it flows through the heat pump it is multiplied by the seasonal performance factor of the heat pump, and incurs a cost equal to the annualized capital cost of the heat pump.

From the conversion device, energy may flow to any of 8 levels of thermal integrity for each building type. In Figure 2, from the burner there are 32 possible paths (4 building types and 8 levels of thermal integrity).

Levels of thermal integrity are represented by 8 thermal shells for each building type. Shells 1 to 4 represent existing stock: shell 1 refers to an existing building without special conservation options and shells 2 to 4 refer to existing buildings with increasing levels of conservation features. Similarly, for new buildings, shell 5 refers to a base building without any special conservation technology options (see

Appendix B for building and conservation technology data).

A flow from the burner to a single family inherited shell with no additional insulation (shell 1) would be multiplied by the efficiency of the shell (1.0) and incur a cost of zero (since no energy-conserving capital stock has been purchased). A flow from the burner to an inherited shell retrofitted with energy-conservation features would have a higher efficiency and would incur a cost equal to the annualized capital cost of the conservation technologies implemented in that shell.

The flow from each shell enters the node representing total housing stock, where it is multiplied by the inverse of the theoretical load for that building type. This coefficient converts energy flow to actual numbers of housing units, or, conversely, it converts right-hand sides for the model, which are in physical units, (housing units in the residential sector and square feet in the commercial) to energy demands for each shell.

The air conditioning, thermal applications, and appliances for both the residential and commercial sectors are modeled in a similar way. Thermal applications include water heating, cooking and drying. The appliances category includes refrigeration, power loads (elevators, escalators, etc.) and miscellaneous electrical appliances.

2.2. Economic Structure

Flows of energy into the buildings network incur a cost equal to the price of the relevant energy form. The flow is allowed to take any of the paths corresponding to a conversion device and shell combination as long as the total demand and other constraints described below are met.

When the energy flows through a node of the network (a conversion or shell technology), it is multiplied by the efficiency of that technology and charged the annualized capital charge for that technology. The optimization makes a lowest-cost tradeoff to invest just the right amount in energy-conserving capital stock to improve efficiency to the point at which the lowest total cost of annualized capital plus the lowest total fuel cost is achieved.

Capital investments are charged an annual charge which is found by multiplying the initial investment by a capital recovery factor to calculate the annual payment required to retire the investment in a certain number of years.

$$\text{Capital recovery factor} = \frac{i}{1 - (1 + i)^{-n}}$$

where i is the long-term discount rate and n is the equipment lifetime in years.

Different equipment lifetimes and discount rates are used for residential and commercial markets and for new and retrofit technologies. These are input parameters in the model and can be easily varied.

The capital charges are applied to incremental investments from the 1975 base year building stock. That is, equipment existing in 1975 is not charged for capital cost, but post-1975 retrofits of existing buildings and investment in new construction are. This means that the optimized capital stock derived in this way represents a preferred investment strategy for the period 1976 through the case year for which the model is programmed, on the assumption that decision makers act as though the case year prices are maintained from 1976 on.

2.3. Structure of the Equations

BESOM and BECOM are run simultaneously as a cost minimization problem. The BESOM equations will be described in detail elsewhere.[5] They may be classified as follows.

1. Supply equations limit the amount of a given resource that may be used in the planning year, either in total use or for a specific purpose. The constraints are given in terms of the energy content of the primary fuel (minemouth and wellhead) input to that supply category. For synthetic fuels and pumped storage, the supply constraint equations represent the energy content of the synthetic fuel after manufacturing.

2. Demand equations specify the energy requirements that must be met in order to satisfy demands from the demand sectors. They are specified as basic energy demands; each basic energy demand is defined as the amount of energy required to support an energy-utilizing activity assuming that the energy could be used at a reference technical efficiency (after conversion). Basic energy demands are specified for each of the demand categories.

3. Electrical supply and peaking constraint equations limit the electrical generating capacity of plant types as well as accounting for peak electric demands and energy balances. The peaking equations are of two types, weekly and seasonal, and describe off-peak power availability.

4. Environmental constraints limit emissions of various types, such as SO_x or particulates. However, in most model runs these constraints are not binding and serve only to sum up environmental effects.

5. Market penetration equations limit the technology penetration of markets, and relate to minimum or maximum levels of fuel use or permitted capacity of a particular type.

BECOM constraints may be grouped in the following classes.

1. Demand constraints. For each type of demand and building type, the flow from all shells to final demand must equal the theoretical building load times the building stock in the year for which consumption is projected.

$$\sum_{j=1}^{8} \frac{1}{a_k} \chi_{jk} = b_k \qquad \text{for all building types } k$$

where

a_k = theoretical building load,

b_k = total stock, and

χ_{jk} = flow from shell j to building k.

2. Minimum constraints on residual stock. The optimization is conducted for a given year subject to the constraint that the number of dwelling units of a particular type heated by any given fuel must equal the number that actually existed in the base year (1975) minus the removals in the period from the base to the year for which the analysis is performed.

$$\sum_{j=1}^{4} \frac{1}{a_k} e_j d_i \chi_{ij} = b_{ik} \qquad \text{for each conversion device } i \text{ and shell } j, \text{ for each building type } k$$

where

e_j = efficiency of shell j,

b_{ik} = total inherited stock (in physical units) of building type k with conversion device i,

a_k = theoretical load for building type k,

d_i = fuel adjustment factor for conversion device i, and

χ_{ij} = flow from conversion device i to shell j.

3. Seasonal load balance. In order to ensure that the heating, air-conditioning, thermal, and appliance loads for each shell are balanced, an equation exists for each shell setting this balance.

$$\chi_{jk} - a_k\gamma_{jk} = 0 \qquad \text{for all shells j to building types k}$$

where

χ_{jk} = space-heating flow from shell j to total building type k,

a_k = ratio of space-heating to air-conditioning load for building type k, and

γ_{jk} = air-conditioning flow from shell j to building type k.

4. Fuel mix in new construction. The market shares of oil, gas, electric, and solar heated units are set in these equations reflecting current construction trends or the results of housing models.

$$q_{ik}n_k \leq \sum_{i=1}^{r} \sum_{j=5}^{8} \frac{1}{a_k} d_i e_j \chi_{ij} \leq p_{ik}n_k \qquad \text{for all building types k}$$

where

a_k = theoretical load of building type k,

d_i = fuel adjustment factor,

e_j = efficiency of shell j,

χ_{ij} = flow from conversion device i to shell j,

p_{ik} = upper limit in percent market penetration for fuel i in building type k,

q_{ik} = lower limit in percent market penetration for fuel i in building type k,

n_k = new construction of building type k, and

r = number of conversion devices using fuel i.

5. Seasonal operation constraints on heat pumps. Electric and gas heat pumps are constrained to have a ratio of heating and cooling equal to the ratio of heating/cooling loads for the relevant shell, building type, and region.

$$e_j\chi_{ij} - kf_j\gamma_{ij} = 0 \qquad \text{for all heat pumps, for all shells in each building type}$$

where

χ_{ij} = space-heating flow from heat pump i to shell j,

γ_{ij} = air-conditioning flow from heat pump i to shell j,

e_j = efficiency of shell j in the heating season,

f_j = efficiency of shell j in the cooling season, and

k = ratio of space-heating to cooling load.

6. Solar back up constraints. These equations require that the use of solar energy be accompanied by a certain fraction

of back up from conventional energy sources to provide heating or cooling when insolation is insufficient. There is an equation for all new shells in each building type for solar space heating, air conditioning, and water heating. The fraction of back up varies depending on end use.

$$\chi_{bj} = f_l \chi_{sj}$$ for all shells j, for all building types, for each end use l

where

χ_{bj} = flow from backup device to shell j,

χ_{sj} = flow from solar unit to shell j, and

f_l = fraction of load provided by backup device.

7. Solar AC constraints. These equations ensure that solar air conditioning can occur only in buildings that employ solar space heating, recognizing that solar air conditioning is never used by itself.

$$\chi_{sj} \geq h\chi_{aj}$$ for all shell j, for all building types

where

χ_{sj} = solar space heat to shell j,

χ_{aj} = solar air conditioning to shell j, and

h = ratio of heating to air-conditioning loads.

8. Solar water heating. These equations ensure that buildings employing solar space-heating systems derive their hot water from the same system.

$$\chi_{tj} \geq k\chi_{sj}$$ for all shells j, for all building types

where

χ_{tj} = solar water heating to shell j,

χ_{sj} = solar space heating to shell j, and

k = ratio of water-heating load to space-heating load.

3. Data Inputs

Within the network flow conception we have outlined, internally consistent performance and cost data are used, taken from the Arthur D. Little data base for buildings[6] summarized in Appendices A and B. The main categories of data are the following.

1. Building stocks. These include inventory data for 1975 for four types of residences and five types of commercial buildings, removals in the period 1976-2000, new construction by type during 1976-2000, and total building stocks.

2. Theoretical building loads. These are defined as the energy required from any conversion device for the reference shell for various types of loads. They are different for different buildings types and different climatic conditions in various regions. They are specified for each region for reference structural technologies for the following categories: space heating, air conditioning, hot water, lighting plus power, and auxiliaries in commercial buildings.

3. Shell efficiencies. These are the percentage improvements in structural integrity, over a nominal 1975 value for new and existing buildings, which can be expected from implementation of certain technologies applicable to building envelopes.

4. Conversion-device efficiencies. These are the percentages of delivered energy which can actually be applied to the theoretical building loads. For heat pumps, for example, this corresponds to the seasonal performance factor.

5. Technology costs. These include the cost for conversion devices and structural technologies, both for new

buildings and for retrofit applications.

Other efforts have been made at BNL and elsewhere[7] to develop improved data for this model, and these will be continued. The ADL data base is being used currently because of its completeness and internal consistency and the extensive experience it embodies.

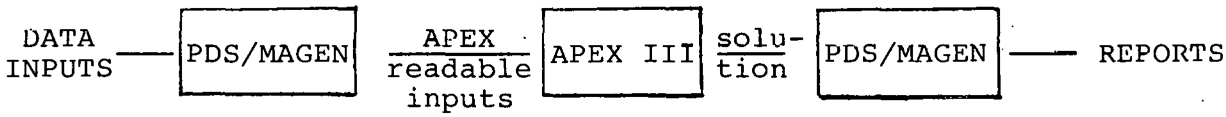
4. Model Operation and Outputs

The equations for the model are set up by using the Haverly Systems, Inc., general-purpose problem-description system (PDS/MAGEN), which contains a bidirectional interface to the Control Data Corporation APEX III linear programming system. The model is run on the APEX III out-of-core system-1 under control of the SCOPE 2.1 operating system on Brookhaven's Control Data 7600 series computer.

Using PDS/MAGEN, a single control file generates the equations, with data inputs being stored in separate files (one for each region). Though each region uses the same control program, a run for any region is independent of the runs for the other regions.

For each case to be explored, the data inputs are total building stocks, bounds for building market shares by fuel, technology cost, and performance data, building loads for each end use (space heating, air conditioning, thermal, and appliances), and the relevant fuel prices. BESOM and BECOM are then run simultaneously as a cost-minimization problem. The combined problem has almost 3800 constraints and 6000 variables and takes almost 200 CPU seconds to solve.

Because of the complexity and size of the problem, a simplified format is used to present the output. This is written by using the report-generating features of PDS/MAGEN. The information flow is shown schematically below.



The output for each region is displayed at three different levels of aggregation. The first level, Figures 8 to 16, shows energy demand by building type. Conversion technologies with fuel are listed in the column at left. Structural technologies for both retrofitted and new buildings are listed across the top. Since each building option is in fact a combination of a conversion technology and a structural technology, each path represented by a given combination of fuel-firing device plus shell in the BECOM network is represented by a cell in this matrix. In the output, the fuel delivered ("over the fence") to each conversion device/shell technology combination is reported in the appropriate cell in the matrix. For each case year and policy scenario one of these matrices is prepared for each of nine building types. Retrofit i (or New i) is a category for a set of conservation technologies in buildings. The eight columns correspond to the eight shell definitions outlined earlier. The two-letter designation (SH, AC, TH, AP) in the third column from the left identifies the end use that the conversion device is satisfying. All the numbers are in units of 10^{12} Btu.

The second level of aggregation sums the energy flows separately in residential buildings (Figure 17) and commercial buildings

(Figure 18). This enables one to find the energy demand by conversion device or end use for all buildings in a sector. The third level of aggregation presents net energy demand by fuel and end use for each region (Figure 19).

The regional totals in Figure 19 sum residential and commercial sectors for each region. The sum of these regional tables yields national demand totals by fuels in the two sectors.

Coverage of Output

Regions: Northeast, North Central, South, West

Building types:	Residential--	Commercial--
	Single family	Hospitals
	Low density	Schools
	Multi-family	Retail
	Mobile homes	Offices
		Miscellaneous

In addition, the results of each run are presented in terms of physical units which use each technology combination, expressed in 10^9 square feet for commercial buildings and 10^6 units for residential structures. A sample of this output is included in Figures 20 to 31.

Finally, to facilitate calculation of investment requirements, the investment (in 1975 constant dollars) in energy-related devices and structures during the period from 1976 through the case year is summarized. These data are presented by new and retrofit markets and building types for both devices and structures. These outputs are illustrated in Figures 32 to 35.

REGION NORTH EAST MARKET HOSPITAL YEAR 1990 -E12BTU-

		RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD	SH	14.065								14.065
GAS BURNER NEW	SH						3.219			3.219
GAS HEAT PUMP	SH						5.745			5.745
OIL BURNER OLD	SH	55.356								55.356
OIL BURNER NEW	SH						6.137			6.137
ELEC. HEAT PUMP	SH									
ELEC. RESISTANCE	SH	0.066								0.066
SOLAR COLLECTOR	SH						1.878			1.878
GAS HEAT PUMP	AC						6.790			6.790
ELEC. HEAT PUMP	AC									
ELEC. ROOM	AC	3.423								3.423
SOLAR COLLECTOR	AC						1.258			1.258
GAS BURNER OLD	TH	3.307								3.307
GAS BURNER NEW	TH						4.073			4.073
OIL BURNER OLD	TH	8.832								8.832
OIL BURNER NEW	TH						1.609			1.609
ELEC. RESISTANCE	TH									
SOLAR COLLECTOR	TH						0.782			0.782
ELEC. LIGHTING APP	AP	37.037					27.207			64.245

Figure 8. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET SCHOOL YEAR 1990 -E12ETU-

	RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD SH	29.600								29.600
GAS BURNER NEW SH						10.546			10.546
GAS HEAT PUMP SH						0.800			0.800
OIL BURNER OLD SH		102.055							102.055
OIL BURNER NEW SH						4.845			4.845
ELEC. HEAT PUMP SH									
ELEC. RESISTANCE SH	0.140								0.140
SOLAR COLLECTOR SH						1.569			1.569
GAS HEAT PUMP AC						0.728			0.728
ELEC. HEAT PUMP AC									
ELEC. ROOM AC	0.757	2.232							2.989
SOLAR COLLECTOR AC						0.809			0.809
GAS BURNER OLD TH	1.132								1.132
GAS BURNER NEW TH						0.789			0.789
OIL BURNER OLD TH	0.004	3.986							3.989
OIL BURNER NEW TH						0.312			0.312
ELEC. RESISTANCE TH		0.260							0.260
SOLAR COLLECTOR TH						0.151			0.151
ELEC. LIGHTING APP AP	7.039	24.868				12.624			44.530

Figure 9. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET OFFICE YEAR 1990 -E12BTU-

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH		35.484							35.484
GAS	BURNER NEW	SH						13.437			13.437
GAS	HEAT PUMP	SH						6.295			6.295
OIL	BURNER OLD	SH		75.615							75.615
OIL	BURNER NEW	SH						6.002	4.016		10.018
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	13.175								13.175
SOLAR	COLLECTOR	SH							2.895		2.895
GAS	HEAT PUMP	AC						6.195			6.195
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	3.673	5.830							9.503
SOLAR	COLLECTOR	AC							1.514		1.514
GAS	BURNER OLD	TH	1.320								1.320
GAS	BURNER NEW	TH						1.460			1.460
OIL	BURNER OLD	TH	0.966	3.418							4.384
OIL	BURNER NEW	TH						0.325	0.229		0.555
ELEC.	RESISTANCE	TH		0.277							0.277
SOLAR	COLLECTOR	TH							0.255		0.255
ELEC.	LIGHTING APP	AP	17.857	32.563				17.308	6.130		73.858

Figure 10. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST   MARKET RETAIL   YEAR 1990   -E12BTU-

	RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD SH			11.804						11.804
GAS BURNER NEW SH						5.415			5.415
GAS HEAT PUMP SH						3.425			3.425
OIL BURNER OLD SH			47.105						47.105
OIL BURNER NEW SH						5.040			5.040
ELEC. HEAT PUMP SH									
ELEC. RESISTANCE SH	0.098								0.098
SOLAR COLLECTOR SH						1.455			1.455
GAS HEAT PUMP AC						7.364			7.364
ELEC. HEAT PUMP AC									
ELEC. ROOM AC	0.062		5.884						5.946
SOLAR COLLECTOR AC									
GAS BURNER OLD TH	0.023		0.507						0.531
GAS BURNER NEW TH						0.908			0.908
OIL BURNER OLD TH			1.985						1.985
OIL BURNER NEW TH						0.359			0.359
ELEC. RESISTANCE TH			0.129						0.129
SOLAR COLLECTOR TH						0.174			0.174
ELEC. LIGHTING APP AP	0.589		70.168			45.901			116.658

Figure 11. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET MISC. YEAR 1990 -E12BTU-

		RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD	SH	29.974								29.974
GAS BURNER NEW	SH						31.567			31.567
GAS HEAT PUMP	SH									
OIL BURNER OLD	SH	11.789								11.789
OIL BURNER NEW	SH						10.044			10.044
ELEC. HEAT PUMP	SH									
ELEC. RESISTANCE	SH	18.928					0.341			19.269
SOLAR COLLECTOR	SH									
GAS HEAT PUMP	AC									
ELEC. HEAT PUMP	AC									
ELEC. ROOM	AC	14.807					5.940			20.747
SOLAR COLLECTOR	AC									
GAS BURNER OLD	TH	1.233								1.233
GAS BURNER NEW	TH						2.253			2.253
OIL BURNER OLD	TH	4.640								4.640
OIL BURNER NEW	TH						0.699			0.699
ELEC. RESISTANCE	TH	0.303								0.303
SOLAR COLLECTOR	TH									
ELEC. LIGHTING APP	AP	94.174					60.324			154.498

Figure 12. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET SINGLE FAMILY YEAR 1990 -E12ETU-

	RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD SH	453.507								453.507
GAS BURNER NEW SH						74.076			74.076
GAS HEAT PUMP SH									
OIL BURNER OLD SH		963.880							963.880
OIL BURNER NEW SH						15.465			15.465
ELEC. HEAT PUMP SH						25.694			25.694
ELEC. RESISTANCE SH	15.911								15.911
SOLAR COLLECTOR SH									
GAS HEAT PUMP AC									
ELEC. HEAT PUMP AC						2.345			2.345
ELEC. ROOM AC	2.749	3.412				0.426			6.587
SOLAR COLLECTOR AC									
GAS BURNER OLD TH		274.066							274.066
GAS BURNER NEW TH						55.925			55.925
OIL BURNER OLD TH	230.216								230.216
OIL BURNER NEW TH						9.321			9.321
ELEC. RESISTANCE TH	23.124	26.208				21.054			70.386
SOLAR COLLECTOR TH									
ELEC. LIGHTING APP AP	67.374	92.921				36.975			197.269

Figure 13. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET LOW DENSITY YEAR 1990 -E12BTU-

		RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD	SH	181.919								181.919
GAS BURNER NEW	SH						22.351			22.351
GAS HEAT PUMP	SH									
OIL BURNER OLD	SH		377.177							377.177
OIL BURNER NEW	SH						4.666			4.666
ELEC. HEAT PUMP	SH						6.901			6.901
ELEC. RESISTANCE	SH	5.973								5.973
SOLAR COLLECTOR	SH									
GAS HEAT PUMP	AC									
ELEC. HEAT PUMP	AC						0.615			0.615
ELEC. ROOM	AC	1.336	1.656				0.182			3.173
SOLAR COLLECTOR	AC									
GAS BURNER OLD	TH	29.116	24.656							53.772
GAS BURNER NEW	TH						6.353			6.353
OIL BURNER OLD	TH		45.169							45.169
OIL BURNER NEW	TH						1.059			1.059
ELEC. RESISTANCE	TH	9.679					2.392			12.071
SOLAR COLLECTOR	TH									
ELEC. LIGHTING APP.	AP	36.200	49.840				12.300			98.340

Figure 14. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET MULTI-FAMILY YEAR 1990 -E12BTU-

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH			133.473						133.473
GAS	BURNER NEW	SH						7.453			7.453
GAS	HEAT PUMP	SH						4.588	0.488		5.076
OIL	BURNER OLD	SH		130.605							130.605
OIL	BURNER NEW	SH						1.387	2.439		3.827
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	2.363					4.293			6.656
SOLAR	COLLECTOR	SH						2.080			2.080
GAS	HEAT PUMP	AC						1.241	0.130		1.371
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0.140	1.392	0.919						2.452
SOLAR	COLLECTOR	AC						0.319			0.319
GAS	BURNER OLD	TH	3.012	30.278							33.291
GAS	BURNER NEW	TH						5.690			5.690
OIL	BURNER OLD	TH		9.777	17.285						27.063
OIL	BURNER NEW	TH							1.282		1.282
ELEC.	RESISTANCE	TH			5.707			2.897			8.604
SOLAR	COLLECTOR	TH						1.403			1.403
ELEC.	LIGHTING APP	AP	2.502	33.315	21.688			15.151	1.407		74.064

Figure 15. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET MOBILE HOME YEAR 1990 -E12BTU-

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH		6.360							6.360
GAS	BURNER NEW	SH						6.124			6.124
GAS	HEAT PUMP	SH						3.951			3.951
OIL	BURNER OLD	SH		15.556							15.556
OIL	BURNER NEW	SH						2.431			2.431
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	0.312					3.951			4.263
SOLAR	COLLECTOR	SH									
GAS	HEAT PUMP	AC						1.360			1.360
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0.009	0.156							0.165
SOLAR	COLLECTOR	AC									
GAS	BURNER OLD	TH	0.217	2.001							2.218
GAS	BURNER NEW	TH						3.406			3.406
OIL	BURNER OLD	TH		1.860							1.860
OIL	BURNER NEW	TH						0.809			0.809
ELEC.	RESISTANCE	TH		0.399				1.350			1.749
SOLAR	COLLECTOR	TH									
ELEC.	LIGHTING APP	AP	0.221	4.371				7.364			11.956

Figure 16. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET COMMERCIAL YEAR 1990 -E12BTU-

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH	73.640	35.484	11.804						120.928
GAS	BURNER NEW	SH						64.184			64.184
GAS	HEAT PUMP	SH						16.264			16.264
OIL	BURNER OLD	SH	67.145	177.670	47.105						291.919
OIL	BURNER NEW	SH						32.067	4.016		36.083
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	32.407					0.341			32.748
SOLAR	COLLECTOR	SH						4.902	2.895		7.798
GAS	HEAT PUMP	AC						21.077			21.077
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	22.722	8.061	5.884			5.940			42.607
SOLAR	COLLECTOR	AC						2.067	1.514		3.581
GAS	BURNER OLD	TH	7.015		0.507						7.522
GAS	BURNER NEW	TH						9.483			9.483
OIL	BURNER OLD	TH	14.441	7.404	1.985						23.830
OIL	BURNER NEW	TH						3.304	0.229		3.534
ELEC.	RESISTANCE	TH	0.303	0.537	0.129						0.969
SOLAR	COLLECTOR	TH						1.107	0.255		1.363
ELEC.	LIGHTING APP	AP	156.695	57.431	70.168			163.364	6.130		453.789

Figure 17. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET RESIDENTIAL YEAR 1990 -E12BTU-

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH	635.426	6.360	133.473						775.259
GAS	BURNER NEW	SH						110.004			110.004
GAS	HEAT PUMP	SH						8.539	0.488		9.026
OIL	BURNER OLD	SH		1487.218							1487.218
OIL	BURNER NEW	SH						23.949	2.439		26.388
ELEC.	HEAT PUMP	SH						32.595			32.595
ELEC.	RESISTANCE	SH	24.559					8.244			32.803
SOLAR	COLLECTOR	SH						2.080			2.080
GAS	HEAT PUMP	AC						2.601	0.130		2.731
ELEC.	HEAT PUMP	AC						2.960			2.960
ELEC.	ROOM	AC	4.234	6.616	0.919			0.608			12.377
SOLAR	COLLECTOR	AC						0.319			0.319
GAS	BURNER OLD	TH	32.345	331.002							363.347
GAS	BURNER NEW	TH						71.374			71.374
OIL	BURNER OLD	TH	230.216	56.806	17.285						304.307
OIL	BURNER NEW	TH						11.188	1.282		12.471
ELEC.	RESISTANCE	TH	32.803	26.606	5.707			27.693			92.810
SOLAR	COLLECTOR	TH						1.403			1.403
ELEC.	LIGHTING APP	AP	106.296	180.446	21.688			71.790	1.407		381.629

Figure 18. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST SUMMARY YEAR 1990 -E15ETU-

COMMERCIAL
****

	SPACE HEAT	AIR CONDITIONING	THERMAL	APPLIANCE
GAS	0.1419	0.0179	0.0112	
OIL	0.1676		0.0140	
ELEC.	0.0327	0.0895	0.0010	0.4538
SCLAR	0.0078	0.0036	0.0014	

RESIDENTIAL
****

	SPACE HEAT	AIR CONDITIONING	THERMAL	APPLIANCE
GAS	0.5557	0.0023	0.2680	
CIL	0.7594		0.1596	
ELEC.	0.0817	0.0322	0.0928	0.3816
SCLAR	0.0021	0.0003	0.0014	

Figure 19. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST   MARKET HOSPITAL   YEAR 1990   E9 SQ,FT,

			RETROFIT NO CONSERV,	RETROFIT 1 CONSERV,	RETROFIT 2 CONSERV,	RETROFIT 3 CONSERV,	NEW NO CONSERV,	NEW 1 CONSERV,	NEW 2 CONSERV,	NEW 3 CONSERV,	TOTAL
GAS	BURNER OLD	SH	0.087								0,087
GAS	BURNER NEW	SH						0,039			0,039
GAS	HEAT PUMP	SH						0,236			0,236
OIL	BURNER OLD	SH	0.311								0,311
OIL	BURNER NEW	SH						0,063			0,063
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	0,002								0,002
SOLAR	COLLECTOR	SH						0,103			0,103
GAS	HEAT PUMP	AC						0,236			0,236
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0,248								0,248
SOLAR	COLLECTOR	AC						0,103			0,103
GAS	BURNER OLD	TH	0.124								0,124
GAS	BURNER NEW	TH						0,187			0,187
OIL	BURNER OLD	TH	0,276								0,276
OIL	BURNER NEW	TH						0,063			0,063
ELEC.	RESISTANCE	TH									
SOLAR	COLLECTOR	TH						0,103			0,103
ELEC.	LIGHTING APP	AP	0.400					0,302			0,702

Figure 20. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET SCHOOL YEAR 1990 E9 SQ.FT.

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH	0.222								0.222
GAS	BURNER NEW	SH						0.177			0.177
GAS	HEAT PUMP	SH						0.043			0.043
OIL	BURNER OLD	SH		0.802							0.802
OIL	BURNER NEW	SH						0.070			0.070
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	0.005								0.005
SOLAR	COLLECTOR	SH						0.113			0.113
GAS	HEAT PUMP	AC						0.043			0.043
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0.057	0.201							0.257
SOLAR	COLLECTOR	AC						0.113			0.113
GAS	BURNER OLD	TH	0.226								0.226
GAS	BURNER NEW	TH						0.206			0.206
OIL	BURNER OLD	TH	0.001	0.709							0.710
OIL	BURNER NEW	TH						0.070			0.070
ELEC.	RESISTANCE	TH		0.093							0.093
SOLAR	COLLECTOR	TH						0.113			0.113
ELEC.	LIGHTING APP	AP	0.227	0.802				0.332			1.361

Figure 21. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET OFFICE YEAR 1990 E9 SQ,FT,

			RETROFIT NO CONSERV,	RETROFIT 1 CONSERV,	RETROFIT 2 CONSERV,	RETROFIT 3 CONSERV,	NEW NO CONSERV,	NEW 1 CONSERV,	NEW 2 CONSERV,	NEW 3 CONSERV,	TOTAL
GAS	BURNER OLD	SH		0,263							0,263
GAS	BURNER NEW	SH						0,186			0,186
GAS	HEAT PUMP	SH						0,288			0,288
OIL	BURNER OLD	SH		0,512							0,512
OIL	BURNER NEW	SH						0,071	0,055		0,126
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	0.425								0,425
SOLAR	COLLECTOR	SH							0,204		0,204
GAS	HEAT PUMP	AC						0,288			0,288
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0.234	0,426							0,660
SOLAR	COLLECTOR	AC							0,204		0,204
GAS	BURNER OLD	TH	0.264								0,264
GAS	BURNER NEW	TH						0.372			0,372
OIL	BURNER OLD	TH	0.161	0,667							0,828
OIL	BURNER NEW	TH						0,071	0,055		0,126
ELEC.	RESISTANCE	TH		0,108							0,108
SOLAR	COLLECTOR	TH							0,204		0,204
ELEC.	LIGHTING APP	AP	0.425	0,775				0.443	0.157		1,800

Figure 22. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET RETAIL YEAR 1990 E9 SQ,FT,

		RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS BURNER OLD	SH			0,184						0,184
GAS BURNER NEW	SH						0,147			0,147
GAS HEAT PUMP	SH						0,336			0,336
OIL BURNER OLD	SH			0,651						0,651
OIL BURNER NEW	SH						0,118			0,118
ELEC. HEAT PUMP	SH									
ELEC. RESISTANCE	SH	0,007								0,007
SOLAR COLLECTOR	SH						0,190			0,190
GAS HEAT PUMP	AC						0,336			0,336
ELEC. HEAT PUMP	AC									
ELEC. ROOM	AC	0,004		0,417						0,421
SOLAR COLLECTOR	AC									
GAS BURNER OLD	TH	0,007		0,178						0,185
GAS BURNER NEW	TH						0,347			0,347
OIL BURNER OLD	TH			0,581						0,581
OIL BURNER NEW	TH						0,118			0,118
ELEC. RESISTANCE	TH			0,076						0,076
SOLAR COLLECTOR	TH						0,190			0,190
ELEC. LIGHTING APP	AP	0,007		0,835			0,560			1,402

Figure 23. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET MISC, YEAR 1990 E9 SQ,FT,

			RETROFIT NO CONSERV,	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV,	RETROFIT 3 CONSERV,	NEW NO CONSERV,	NEW 1 CONSERV,	NEW 2 CONSERV,	NEW 3 CONSERV,	TOTAL
GAS	BURNER OLD	SH	0.367								0,367
GAS	BURNER NEW	SH						0,859			0,859
GAS	HEAT PUMP	SH									
OIL	BURNER OLD	SH	0.131								0,131
OIL	BURNER NEW	SH						0,234			0,234
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	1,183					0,022			1,205
SOLAR	COLLECTOR	SH									
GAS	HEAT PUMP	AC									
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0,840					0,670			1,510
SOLAR	COLLECTOR	AC									
GAS	BURNER OLD	TH	0.370								0,370
GAS	BURNER NEW	TH						0,882			0,882
OIL	BURNER OLD	TH	1.160								1,160
OIL	BURNER NEW	TH						0,234			0,234
ELEC.	RESISTANCE	TH	0,151								0,151
SOLAR	COLLECTOR	TH									
ELEC.	LIGHTING APP	AP	1.681					1,116			2,797

Figure 24. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET SINGLE FAMILY YEAR 1990 E6 UNITS

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH	2.895								2,895
GAS	BURNER NEW	SH						0,836			0,836
GAS	HEAT PUMP	SH									
OIL	BURNER OLD	SH		4,423							4,423
OIL	BURNER NEW	SH						0,150			0,150
ELEC.	HEAT PUMP	SH						0,774			0,774
ELEC.	RESISTANCE	SH	0.312								0,312
SOLAR	COLLECTOR	SH									
GAS	HEAT PUMP	AC									
ELEC.	HEAT PUMP	AC						0,774			0,774
ELEC.	ROOM	AC	0.962	1,327				0,141			2,430
SOLAR	COLLECTOR	AC									
GAS	BURNER OLD	TH		3,815							3,815
GAS	BURNER NEW	TH						1,047			1,047
OIL	BURNER OLD	TH	2.670								2,670
OIL	BURNER NEW	TH						0,150			0,150
ELEC.	RESISTANCE	TH	0.536	0,608				0,563			1,708
SOLAR	COLLECTOR	TH									
ELEC.	LIGHTING APP	AP	3.207	4,423				1,760			9,390

Figure 25. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET LOW DENSITY YEAR 1990 E6 UNITS

		RETROFIT NO CONSERV,	RETROFIT 1 CONSERV,	RETROFIT 2 CONSERV,	RETROFIT 3 CONSERV,	NEW NO CONSERV,	NEW 1 CONSERV,	NEW 2 CONSERV,	NEW 3 CONSERV,	TOTAL
GAS BURNER OLD	SH	1.629								1,629
GAS BURNER NEW	SH						0,292			0,292
GAS HEAT PUMP	SH									
OIL BURNER OLD	SH		2,492							2,492
OIL BURNER NEW	SH						0,052			0,052
ELEC. HEAT PUMP	SH						0,271			0,271
ELEC. RESISTANCE	SH	0.181								0,181
SOLAR COLLECTOR	SH									
GAS HEAT PUMP	AC									
ELEC. HEAT PUMP	AC						0.271			0,271
ELEC. ROOM	AC	0,561	0,773				0,080			1,414
SOLAR COLLECTOR	AC									
GAS BURNER OLD	TH	1.165	0,986							2,151
GAS BURNER NEW	TH						0,366			0,366
OIL BURNER OLD	TH		1,506							1,506
OIL BURNER NEW	TH						0,052			0,052
ELEC. RESISTANCE	TH	0,645					0,197			0,842
SOLAR COLLECTOR	TH									
ELEC. LIGHTING APP	AP	1.810	2.492				0,615			4,917

Figure 26. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET MULTI-FAMILY YEAR 1990 E6 UNITS

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH			1,205						1,205
GAS	BURNER NEW	SH						0,163			0,163
GAS	HEAT PUMP	SH						0,472	0,057		0,529
OIL	BURNER OLD	SH		1,851							1,851
OIL	BURNER NEW	SH						0,026	0,052		0,078
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	0,139					0,294			0,433
SOLAR	COLLECTOR	SH						0,285			0,285
GAS	HEAT PUMP	AC						0,472	0,057		0,529
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM-	AC	0,074	0,981	0,639						1,693
SOLAR	COLLECTOR	AC						0,285			0,285
GAS	BURNER OLD	TH	0,139	1,459							1,598
GAS	BURNER NEW	TH						0,405			0,405
OIL	BURNER OLD	TH		0,392	0,726						1,118
OIL	BURNER NEW	TH							0,078		0,078
ELEC.	RESISTANCE	TH			0,479			0,294			0,774
SOLAR	COLLECTOR	TH						0,285			0,285
ELEC.	LIGHTING APP	AP	0,139	1,851	1,205			0,842	0,078		4,115

Figure 27. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST MARKET MOBILE HOME YEAR 1990 E6 UNITS

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH		0,102							0,102
GAS	BURNER NEW	SH						0,108			0,108
GAS	HEAT PUMP	SH						0,208			0,208
OIL	BURNER OLD	SH		0,155							0,155
OIL	BURNER NEW	SH						0,037			0,037
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	0.013					0,139			0,152
SOLAR	COLLECTOR	SH									
GAS	HEAT PUMP	AC						0,208			0,208
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	0,003	0,064							0,068
SOLAR	COLLECTOR	AC									
GAS	BURNER OLD	TH	0.013	0,122							0,135
GAS	BURNER NEW	TH						0,245			0,245
OIL	BURNER OLD	TH		0,094							0,094
OIL	BURNER NEW	TH						0,050			0,050
ELEC.	RESISTANCE	TH		0,040				0,139			0,179
SOLAR	COLLECTOR	TH									
ELEC.	LIGHTING APP	AP	0.013	0,257				0,433			0,703

Figure 28. Buildings energy conservation cptimization model. Case-base policy.

REGION NORTH EAST MARKET COMMERCIAL YEAR 1990 E9 SQ.FT.

			RETROFIT NO CONSERV.	RETROFIT 1 CONSERV.	RETROFIT 2 CONSERV.	RETROFIT 3 CONSERV.	NEW NO CONSERV.	NEW 1 CONSERV.	NEW 2 CONSERV.	NEW 3 CONSERV.	TOTAL
GAS	BURNER OLD	SH	0.676	0.263	0.184						1.123
GAS	BURNER NEW	SH						1.408			1.408
GAS	HEAT PUMP	SH						0.903			0.903
OIL	BURNER OLD	SH	0.442	1.314	0.651						2.407
OIL	BURNER NEW	SH						0.556	0.055		0.611
ELEC.	HEAT PUMP	SH									
ELEC.	RESISTANCE	SH	1.622					0.022			1.644
SOLAR	COLLECTOR	SH						0.406	0.204		0.610
GAS	HEAT PUMP	AC						0.903			0.903
ELEC.	HEAT PUMP	AC									
ELEC.	ROOM	AC	1.383	0.627	0.417			0.670			3.096
SOLAR	COLLECTOR	AC						0.216	0.204		0.420
GAS	BURNER OLD	TH	0.991		0.178						1.169
GAS	BURNER NEW	TH						1.994			1.994
OIL	BURNER OLD	TH	1.598	1.376	0.581						3.555
OIL	BURNER NEW	TH						0.556	0.055		0.611
ELEC.	RESISTANCE	TH	0.151	0.201	0.076						0.428
SOLAR	COLLECTOR	TH						0.406	0.204		0.610
ELEC.	LIGHTING APP	AP	2.740	1.577	0.835			2.753	0.157		8.062

Figure 29. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST　　MARKET RESIDENTIAL　　YEAR 1990　　E6 UNITS

			RETROFIT NO CONSERV,	RETROFIT 1 CONSERV,	RETROFIT 2 CONSERV,	RETROFIT 3 CONSERV,	NEW NO CONSERV,	NEW 1 CONSERV,	NEW 2 CONSERV,	NEW 3 CONSERV,	TOTAL
GAS	BURNER OLD	SH	4.524	0,102	1,205						5,831
GAS	BURNER NEW	SH						1,400			1,400
GAS	HEAT PUMP	SH						0,680	0,057		0,737
OIL	BURNER OLD	SH		8,921							8,921
OIL	BURNER NEW	SH						0,265	0,052		0,317
ELEC.	HEAT PUMP	SH						1,045			1,045
ELEC.	RESISTANCE	SH	0.645					0,433			1,078
SOLAR	COLLECTOR	SH						0,285			0,285
GAS	HEAT PUMP	AC						0,680	0,057		0,737
ELEC.	HEAT PUMP	AC						1,045			1,045
ELEC.	ROOM	AC	1,600	3,145	0,639			0,221			5,604
SOLAR	COLLECTOR	AC						0,285			0,285
GAS	BURNER OLD	TH	1.317	6,382							7,699
GAS	BURNER NEW	TH						2,063			2,063
OIL	BURNER OLD	TH	2.670	1,993	0,726						5,389
OIL	BURNER NEW	TH						0,252	0,078		0,330
ELEC.	RESISTANCE	TH	1.182	0,649	0,479			1,193			3,503
SOLAR	COLLECTOR	TH						0,285			0,285
ELEC.	LIGHTING APP	AP	5.169	9,023	1,205			3,650	0,078		19,125

Figure 30. Buildings energy conservation optimization model. Case-base policy.

REGION NORTH EAST SUMMARY YEAR 1990 PHY,UNITS

COMMERCIAL
****

	SPACE HEAT	AIR CONDITIONING	THERMAL	APPLIANCE
GAS	3,4340	0,9027	3,1634	
OIL	3,0181		4,1660	
ELEC.	1,6443	3,0964	0,4277	8,0620
SOLAR	0,6100	0,4196	0,6100	

RESIDENTIAL
****

	SPACE HEAT	AIR CONDITIONING	THERMAL	APPLIANCE
GAS	7,9674	0,7368	9,7611	
OIL	9,2379		5,7188	
ELEC.	2,1229	6,6492	3,5025	19,1250
SOLAR	0,2852	0,2852	0,2852	

Figure 31. Buildings energy conservation optimization model. Case-base policy.

REGION - NORTH EAST RESIDENTIAL YEAR 1990 UNIT - $ BILLION

		NEW		OLD	
SINGLE FAMILY	LEVEL I	1.1483		3.3965	
	LEVEL II				
	LEVEL III		1.1483		3.3965
LOW DENSITY	LEVEL I	0.2968		1.4287	
	LEVEL II				
	LEVEL III		0.2968		1.4287
MULTI-FAMILY	LEVEL I	0.1604		0.6864	
	LEVEL II	0.0276		0.6999	
	LEVEL III		0.1880		1.3864
MOBIL HOME	LEVEL I	0.1714		0.0643	
	LEVEL II				
	LEVEL III		0.1714		0.0643
TOTAL		1.8044		6.2759	

Figure 32. Buildings energy conservation optimization model. Capital investment in structural technologies (1975 $).

REGION - NORTH EAST COMMERCIAL YEAR 1990 UNIT - $ BILLION

****

		NEW		OLD	
		***		***	
HOSPITALS	LEVEL I	0.1046			
	LEVEL II				
	LEVEL III		0.1046		
SCHOOLS	LEVEL I	0.1128		0.5419	
	LEVEL II				
	LEVEL III		0.1128		0.5419
OFFICES	LEVEL I	0.1054		0.3664	
	LEVEL II	0.0920			
	LEVEL III		0.1973		0.3664
RETAIL	LEVEL I	0.1308			
	LEVEL II			0.7108	
	LEVEL III		0.1308		0.7108
MISC	LEVEL I	0.4503			
	LEVEL II				
	LEVEL III		0.4503		
TOTAL		0.9959		1.6191	

Figure 33. Buildings energy conservation optimization model. Capital investment in structural technologies (1975 $).

REGION NORTH EAST RESIDENTIAL YEAR 1990 UNIT - $ BILLION

	SPACE HEAT	AIR COND	THERMAL	APPLIANCE & LIGHT
SINGLE FAMILY	7.3888	0.2551	1.4302	4.1442
LOW DENSITY	2.1610	0.0523	0.1625	1.3786
MULTI-FAMILY	2.9811	0.0896	0.2765	1.8559
MOBIL HOME	0.7026		0.0886	0.8254
TOTAL	13.2334	0.3969	1.9577	8.2041

Figure 34. Buildings energy conservation optimization model. Capital investment in conversion devices (1975 $).

REGION NORTH EAST COMMERCIAL YEAR 1990 UNIT - $ BILLION

	SPACE HEAT	AIR COND	THERMAL	APPLIANCE & LIGHT
HOSPITALS	3.4716	0.2132	0.1234	3.0762
SCHOOLS	1.6330	0.0932	0.0248	1.4273
OFFICES	4.3642	0.2012	0.0451	2.6500
RETAIL	2.7071		0.0267	5.1899
MISC	0.4517	1.8152	0.0354	6.8207
TOTAL	12.6275	2.3227	0.2553	19.1641

Figure 35. Buildings energy conservation optimization model. Capital investment in conversion devices (1975 $).

5. Applications

The most important feature of the model from the point of view of the user is that BECOM consists of a multitude of individually specified building energy technologies which are selected and assembled in a systematic way to project a picture of the entire stock of energy technologies in buildings and the resulting energy consumption. The technologies currently included comprise the major classes of conventional equipment and also major types of equipment under development. Novel and conventional equipment types compete on an equal basis.

These structural characteristics of BECOM make it especially suited for certain types of analysis.

1. Market penetration analysis. Because all types of equipment compete simultaneously, meaningful analyses of the relative roles of various technologies can be developed. Furthermore, since all possible combinations of conversion devices (such as HVAC equipment and various structural improvements) are included, one can analyze the synergistic effects of combining various types of conversion devices and structural technologies. Unlike many other models of buildings energy demand, BECOM makes it is impossible to double-count energy savings.

Because it includes nine building types, two building classes (new and retrofit), and four regions, BECOM can be used to calculate the market penetrations of technologies in considerable detail and also on a national aggregate basis. Thus, the model identified both those technologies that have a large national impact and those that may be highly desirable in a limited market.

2. Policy analysis. A major question before the nation in relation to energy consumption in buildings is the role of various policy measures such as price regulation of various forms of energy, tax incentives for investment in specific building technologies, implementation of various code improvements, and setting of performance standards for appliances, air conditioning, and buildings. BECOM can analyze effects of such measures in a high degree of detail. Various pricing policies can be represented through input prices, which can be varied for different regions and consuming sectors. Tax incentives or other measures for changing the economics of building investment can and have been entered through adjustments to the capital charges for various building types. These adjustments can be different for each type of building just as they are likely to be for different classes of building owners. (Store owners will be treated differently than homeowners, for example.) Finally, regulatory action can be represented through constraints requiring or prohibiting certain technologies in the various markets.

3. Analysis of research, development, and demonstration projects. Because BECOM makes projections of buildings energy demand by assembling an overall technological configuration from many individual technologies, it is particularly well suited to examining the role of these technologies in the context of total building energy consumption.

Within BECOM, a technology is a generic type. For example, the electric heat pump is one generic technology. DOE or other RD&D projects related to electric heat-pump market share for each region or building type (if the project were so directed) indicated by BECOM. If the project were directed at achieving a particular cost or efficiency improvement, these parameters could be entered in the model to estimate the degree to which a given cost or improvement would improve market penetration, and the particular building types and regions where the increased market penetration would occur.

A key feature of BECOM for RD&D assessment is that the simultaneous competition of all technologies precludes double counting of energy savings which could occur if energy savings from technologies were estimated without considering competing technologies. Also, since buildings are defined according to both conversion devices and structural technologies, savings are attributed to the combined effect of conversion-device improvements and structural improvements, as will actually occur in the field.

4. Sensitivity analysis. This type of analysis is closely related to the other areas outlined above. Because of the advanced programming system used for this model, one can quickly perform a series of evaluations of the types outlined, varying a single parameter (an energy price, for example, or the level of a tax credit) and produce a complete analysis of the entire buildings sector for each value of the parameter of

interest. Thus the full effects of a specific decision variable can be thoroughly analyzed.

5. Conservation implementation. BECOM is expected to be used in the near future to study the relationship between implementation of energy-conservation technologies (revealed, for example, through sales figures for insulation, heat pumps, and so forth) and yearly totals for energy consumption in buildings. By reconciling yearly sales totals of building energy technologies and total energy consumption within the BECOM framework, it will be possible to assess whether federal policies are having the anticipated effects on conservation-technology implementation and ultimately on energy consumption. If not, policy adjustments can be assessed.

6. Environmental effects of conservation in buildings. Reduced environmental impacts in the energy supply system as a whole are captured in BESOM. Detailed coefficients for emissions from the individual conversion devices included in BECOM are being developed. When this task is completed, detailed assessments of the environmental effects of buildings conservation policies can be performed.

Acknowledgements

Many persons have made essential contributions to this program. William Marcuse orginally conceived this approach to modeling energy conservation technologies, and he has provided continuing guidance and support. The overall building energy conservation program at BNL has been made possible by continuing interest and support from the Division of Buildings and Community Systems, particularly its director, Dr. Maxine Savitz, and Dr. S. Melvin Chiogioji and Joan Hock. Martin Glesk, leader of the Arthur D. Little case team on buildings, provided invaluable assistance in the form of data presented in the appendices to this report and also working suggestions. Comments from the Market Oriented Program Planning Study Residential and Commercial Working Group were helpful and essential, particularly those of Ed Blum and Eric Hirst.

Invaluable assistance was provided by Doreen Schneider and Marc Raisch of the BNL staff in assembling data and completing calculations. Barbara Nichols, Carmen Zopf, Marge Gallitelli, and Nancy Jesaitis provided their customary efficient and capable services in typing and assembly. Technical drawings were done by Stan Majeski. This effort has greatly benefited from the environment of Brookhaven's National Center for Analysis of Energy Systems, and especially from contact with several members who have worked in this general area - Kenneth Hoffman, Andy Kydes, Andres Doernberg, and Alan Hermelee. Responsibility for the paper remains, of course with the authors.

References

1. Cherniavsky,E.A., Brookhaven Energy System Optimization Model, Informal Report, BNL 19569, 1974.

2. Goldberg, M.D., An Energy Model Data Base, Informal Report, BNL 19200, undated (1973).

3. Beller, M., Editor, Sourcebook for Energy Assessment, BNL 50483, December 1975.

4. Marcuse, W., Carhart, S., and Mulherkar, S., Residential energy demand analysis - Data and methodology, Presented at Joint National Meeting Operations Res. Soc. Am. and Institute of Management Science, Miami, November 1976 (BNL 21920).

5. Cherniavsky, E.A., Kydes, A.S., et al., Brookhaven Energy Systems Optimization Model - Methodology and Documentation (Version 2.1), BNL report, in preparation.

6. Glesk, M., et al., Report to Department of Energy on Building Technologies, Arthur D. Little, Inc., in preparation.

7. Daifuku, R., Residential Space Heating and Cooling in New England 1972-2000, BNL 50614, December 1976.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX A

Residential and Commercial Inventory and Forecasts

RESIDENTIAL CONSTRUCTION INVENTORY FORECASTS

(thousand units)

	1975 INVENTORY	NEW CONSTRUCTION 1976-1980	1981-1985	1986-2000	REMOVALS 1976-2000	2000 INVENTORY
Northeast Total	16,282	1,250	1,500	3,357	1,629	20,760
Single Family Detached	7,910	698	693	1,475	640	10,136
Low Density	4,544	156	246	648	397	5,197
Multi-Family	3,445	252	407	801	409	4,496
Mobile Homes	383	144	154	433	183	931
North Central Total	18,993	2,074	2,505	5,646	2,353	26,865
Single Family Detached	13,253	1,250	1,335	2,926	1,259	17,505
Low Density	2,840	161	235	616	321	3,531
Multi-Family	2,112	340	588	1,134	306	3,868
Mobile Homes	788	323	347	970	467	1,961
South Total	22,488	3,827	4,647	10,504	3,439	38,027
Single Family Detached	16,051	2,330	2,477	5,499	2,014	24,343
Low Density	2,315	280	442	1,106	255	3,888
Multi-Family	2,428	580	1,045	1,988	236	5,805
Mobile Homes	1,694	637	683	1,911	934	3,991
West Total	13,067	2,149	2,628	5,926	1,629	22,141
Single Family Detached	8,379	1,140	1,175	2,553	846	12,401
Low Density	1,740	285	439	1,102	128	3,438
Multi-Family	2,098	428	698	1,385	209	4,400
Mobile Homes	850	296	316	886	446	1,902
U. S. Total	70,830	9,300	11,280	25,433	9,050	107,793

COMMERCIAL CONSTRUCTION INVENTORY FORECASTS

(million square feet)

	1975 INVENTORY	NEW CONSTRUCTION 1976-1980	1981-1985	1986-2000	REMOVALS 1976-2000	2000 INVENTORY
Northeast Total	5,688	938	980	3,272	879	9,999
Office & Bank	1,321	193	203	660	198	2,179
Retail	928	179	190	636	139	1,794
Schools	1,150	114	107	342	199	1,514
Hospitals	440	94	101	368	66	937
Other	1,849	358	379	1,266	277	3,575
North Central Total	6,674	1,169	1,217	4,089	1,135	12,014
Office & Bank	1,317	198	207	675	224	2,173
Retail	1,517	334	354	1,195	258	3,142
Schools	1,812	190	179	576	308	2,449
Hospitals	511	113	122	448	87	1,107
Other	1,517	334	,355	1,195	258	3,143
South Total	7,320	1,273	1,379	4,783	1,464	13,291
Office & Bank	1,650	265	288	975	330	2,848
Retail	1,589	317	349	1,212	318	3,149
Schools	1,530	167	162	540	306	2,093
Hospitals	486	113	127	480	97	1,109
Other	2,065	411	453	1,576	413	4,092
West Total	4,781	811	891	3,106	813	8,776
Office & Bank	1,146	185	203	690	195	2,029
Retail	960	180	202	706	163	1,884
Schools	934	104	102	342	159	1,323
Hospitals	294	70	80	304	50	698
Other	1,447	272	304	1,064	246	2,842
U.S. Total	24,463	4,191	4,467	15,250	4,291	44,080

Building Units and % Air Conditioned - 1976-2000
New - Non Residential 1976-2000

		NEW Built 1976-2000	% A C	RETROFIT 1976-2000	% A C
Northeast	Offices	1,056	65	1,123	55
	Ret. & Other	3,008	60	2,361	50
	Schools	563	30	978	25
	Hospitals	563	95	374	62
North Central	Offices	1,080	65	1,093	50
	Ret. & Other	3,767	60	2,518	45
	Schools	945	50	1,504	32
	Hospitals	683	97	424	56
South	Offices	1,528	95	1,320	70
	Ret. & Other	4,318	90	2,923	65
	Schools	869	75	1,224	60
	Hospitals	720	100	389	75
West	Office	1,078	85	951	60
	Ret. & Other	2,728	80	1,998	55
	Schools	548	70	775	52
	Hospitals	454	100	244	67

Building Units and % Air Conditioned - 1976-2000
New and Retrofit

		New Units 1976-2000	% A C*	Retro Units	% A C*
Northeast	Single Family	2,866	52	7,270	30
	Low Density	1,050	57	4,147	31
	Multi-Family	1,460	73	3,036	53
	Mobile Home	731	48	200	25
North Central	Single Family	5,511	70	11,994	43
	Low Density	1,012	73	2,519	34
	Multi-Family	2,062	87	1,806	67
	Mobile Home	1,640	45	321	30
South	Single Family	10,306	87	14,037	48
	Low Density	1,828	90	2,060	43
	Multi-Family	3,613	95	2,192	77
	Mobile Home	3,231	85	760	35
West	Single Family	4,868	70	7,533	35
	Low Density	1,826	75	1,612	31
	Multi-Family	2,511	82	1,889	39
	Mobile Home	1,498	72	404	35

* Central and Room

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX B

- Theoretical Loads for Buildings
- Conservation Technology Costs and Savings
- First Costs of Conventional HVAC Equipment

THEORETICAL BUILDING ENERGY LOADS

RESIDENTIAL - NEW CONSTRUCTION 1976-1980

Building Type	Region	Heat Fossil	Heat Electric	Cool	Thermal	Light and Power	Aux.
Single-Family	NE	81	65	8	19	21	
	NC	102	81	13	19	23	
	S	39	36	59	19	21	NA
	W	57	53	60	19	23	
Low Density	NE	70	50	6	13	20	
	NC	102	62	11	13	21	
	S	38	28	47	13	20	NA
	W	57	40	48	13	21	
Multi-Family	NE	46	21	3	11	18	
	NC	53	23	5	11	18	
	S	19	11	22	11	17	NA
	W	23	15	21	11	18	
Mobile Homes	NE	57	41	8	8	17	
	NC	66	47	12	8	20	
	S	31	22	38	8	20	NA
	W	38	27	37	8	17	

All figures in 10^6 Btu/unit

Assumes the following conversion efficiencies:

Gas	0.7
Oil	0.6
Electric	1.0
A C CoP	2.1

THEORETICAL BUILDING ENERGY LOADS

COMMERCIAL - NEW CONSTRUCTION 1976-1980

Building Type	Region	Heat Fossil	Heat Electric	Cool	Thermal	Light and Power	Aux.
Office and Bank	NE	68	44	23	3	24	15
	NC	68	51	23	3	30	18
	S	42	24	53	3	30	20
	W	43	25	34	3	31	20
Retail	NE	37	22	25	2	62	20
	NC	44	26	26	2	67	25
	S	18	14	61	2	69	30
	W	23	16	40	2	72	30
Schools	NE	60	40	19	3	26	12
	NC	70	46	19	3	28	15
	S	31	18	43	3	28	18
	W	38	23	25	3	31	18
Hospitals	NE	73	54	19	17	60	30
	NC	86	54	19	17	74	30
	S	37	19	43	17	73	35
	W	46	25	25	17	86	35
Other	NE	37	24	--	2	34	20
	NC	44	27	--	2	35	25
	S	17	15	61	2	37	30
	W	22	16	--	2	39	30

All figures in 10^3 Btu/square foot

Assumes the following conversion efficiencies:

Gas	0.7
Oil	0.6
Electric	1.0
A C CoP	2.1

THEORETICAL BUILDING ENERGY LOADS

RESIDENTIAL - RETROFIT 1975 INVENTORY

Building Type	Region	Gas	Heat Oil	Electric	Cool	Thermal	Light and Power	Aux.
Single-Family	NE	94	128	51	6	22	21	
	NC	118	114	64	19	22	23	
	S	43	79	31	63	22	21	NA
	W	57	102	44	74	22	23	
Low Density	NE	67	89	33	5	15	20	
	NC	87	84	45	11	15	21	
	S	30	54	21	36	15	20	NA
	W	37	65	30	54	15	20	
Multi-Family	NE	43	58	17	4	13	18	
	NC	50	49	24	9	13	18	
	S	16	29	10	34	13	17	NA
	W	20	35	14	33	13	18	
Mobile Homes	NE	44	59	24	6	10	17	
	NC	54	53	29	10	10	20	
	S	21	53	15	40	10	20	NA
	W	27	48	20	46	10	17	

All figures in 10^6 Btu/unit

Assumes the following conversion efficiencies:

Gas	0.6
Oil	0.5
Electric	1.0
A C CoP	2.1

THEORETICAL BUILDING ENERGY LOADS*

COMMERCIAL - RETROFIT 1975 INVENTORY

Building Type	Region	Heat Gas	Heat Oil	Heat Electric	Cool	Thermal	Light and Power	Aux.
Office and Bank	NE	91	83	31	33	3	24	18
	NC	84	68	--	36	-	30	20
	S	64	60	19	87	3	30	22
	W	66	59	20	57	3	31	22
Retail	NE	50	47	14	37	2	62	22
	NC	46	37	--	41	-	67	27
	S	29	26	10	99	2	69	33
	W	35	32	13	68	2	72	33
Schools	NE	80	74	28	28	3	26	15
	NC	74	60	--	30	-	28	18
	S	50	44	14	70	3	28	20
	W	58	52	19	39	3	31	20
Hospitals	NE	97	89	33	42	16	60	32
	NC	90	73	--	45	--	74	32
	S	55	51	14	106	16	73	37
	W	68	61	20	76	16	86	37
Other	NE	49	45	16	37	2	34	22
	NC	46	37	--	41	-	35	27
	S	27	24	11	99	2	37	33
	W	33	30	13	68	2	39	33

All Figures in 10^3 Btu/square foot

Assumes the following conversion efficiencies:

Gas	0.6
Oil	0.5
Electric	1.0
A C CoP	2.1

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: SINGLE FAMILY 1560 SQ. FT. UNIT

		First Cost $/unit	Heating	Cooling	Hot Water	L&P
			CONSERVATION LEVEL I % of load saved			
New Construction	NE	220	23	20	5	5
	NC	220	25	22	5	5
	S	240	23	25	5	5
	W	240	25	23	5	5
Retrofit	NE	260	15	10	0	0
	NC	260	17	10	0	0
	S	200	12	15	0	0
	W	200	14	13	0	0
			CONSERVATION LEVEL II			
New Construction	NE	800	50	35	5	5
	NC	800	52	37	5	5
	S	770	44	35	5	5
	W	770	46	33	5	5
Retrofit	NE	1,130	43	20	0	0
	NC	1,130	45	20	0	0
	S	1,070	37	25	0	0
			CONSERVATION LEVEL III			
New Construction	NE	2,140	58	40	10	5
	NC	2,140	60	42	10	5
	S	1,760	50	40	10	5
	W	1,760	52	38	10	5
Retrofit	NE	1,860	52	25	5	0
	NC	1,860	54	25	5	0
	S	1,770	44	30	5	0
	W	1,770	46	28	5	0

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: LOW DENSITY 1000 SQ. FT. UNIT

		First Cost $/unit	Heating	Cooling	Hot Water	L&P
			CONSERVATION LEVEL I % of load saved			
New Construction	NE	165	23	20	5	5
	NC	165	25	22	5	5
	S	180	23	25	5	5
	W	180	25	23	5	5
Retrofit	NE	195	15	10	0	0
	NC	195	17	10	0	0
	S	150	12	15	0	0
	W	150	14	13	0	0
			CONSERVATION LEVEL II			
New Construction	NE	600	50	35	5	5
	NC	600	52	37	5	5
	S	580	44	35	5	5
	W	580	46	33	5	5
Retrofit	NE	850	43	20	0	0
	NC	850	45	20	0	0
	S	800	37	25	0	0
	W	800	39	23	0	0
			CONSERVATION LEVEL III			
New Construction	NE	1,600	58	40	10	5
	NC	1,600	60	42	10	5
	S	1,320	50	40	10	5
	W	1,320	52	38	10	5
Retrofit	NE	1,400	52	25	5	0
	NC	1,400	54	25	5	0
	S	1,330	44	30	5	0
	W	1,330	46	28	5	0

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: MULTI-FAMILY 900 SQ.FT. UNIT

		First Cost $/unit	Heating	Cooling	Hot Water	L&P	Aux.
			CONSERVATION LEVEL I % of load saved				
New Construction	NE	65	30	25	15	5	10
	NC	65	33	25	15	5	10
	S	65	25	30	15	5	10
	W	65	27	28	15	5	10
Retrofit	NE	126	18	25	8	5	0
	NC	126	21	25	8	5	0
	S	126	17	18	8	5	0
	W	126	20	16	8	5	0
			CONSERVATION LEVEL II				
New Construction	NE	120	38	35	15	5	10
	NC	120	40	35	15	5	10
	S	120	35	42	15	5	10
	W	120	37	40	15	5	10
Retrofit	NE	198	24	25	15	5	0
	NC	198	28	25	15	5	0
	S	198	25	22	15	5	0
	W	198	29	20	15	5	0
			CONSERVATION LEVEL III				
New Construction	NE	260	45	44	20	5	10
	NC	260	48	44	20	5	10
	S	260	40	50	20	5	10
	W	260	42	47	20	5	10
Retrofit	NE	324	24	25	23	5	0
	NC	324	29	25	23	5	0
	S	324	25	22	23	5	0
	W	324	30	18	23	5	0

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: MOBILE HOME 720 SQ. FT. UNIT

		First Cost $/unit	Heating	Cooling	Hot Water	L&P
			CONSERVATION LEVEL I % of load saved			
New Construction	NE	1	30	30	5	0
	NC	1	30	30	5	0
	S	1	20	20	5	0
	W	1	20	20	5	0
Retrofit	NE	85	15	15	3	0
	NC	85	15	15	3	0
	S	85	15	15	3	0
	W	85	15	15	3	0
			CONSERVATION LEVEL II			
New Construction	NE	330	45	45	5	0
	NC	330	45	45	5	0
	S	230	30	30	5	0
	W	230	30	30	5	0
Retrofit	NE	435	30	25	7	0
	NC	435	30	25	7	0
	S	335	25	30	7	0
	W	335	25	30	7	0
			CONSERVATION LEVEL III			
New Construction	NE	790	61	61	7	0
	NC	790	61	61	7	0
	S	490	46	46	7	0
	W	490	46	46	7	0
Retrofit	NE	655	37	28	7	0
	NC	655	37	28	7	0
	S	475	30	33	7	0
	W	475	30	33	7	0

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: OFFICE

		First Cost $/1000 ft^2	Heating	Cooling	Hot Water	L&P	Aux.
			CONSERVATION LEVEL I % of load saved				
New Construction	NE	80	25	20	0	15	10
	NC	80	27	20	0	15	10
	S	80	28	35	0	15	10
	W	80	30	32	0	15	10
Retrofit	NE	160	11	13	0	25	17
	NC	160	13	13	0	25	17
	S	160	6	8	0	20	14
	W	160	8	7	0	20	14
			CONSERVATION LEVEL II				
New Construction	NE	200	35	35	5	25	16
	NC	200	38	35	5	25	16
	S	200	38	45	5	25	16
	W	200	41	42	5	25	16
Retrofit	NE	330	15	17	0	50	28
	NC	330	17	17	0	50	28
	S	330	13	11	0	40	23
	W	330	15	10	0	40	23
			CONSERVATION LEVEL III				
Ne, Construction	NE	465	40	47	10	25	20
	NC	465	43	47	10	25	20
	S	465	45	50	10	25	20
	W	465	48	47	10	25	20
Retrofit	NE	580	23	34	0	50	38
	NC	580	26	34	0	50	38
	S	580	19	24	0	40	32
	W	580	22	22	0	40	32

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: SCHOOL

		First Cost $/1000 ft^2	Heating	Cooling	Hot Water	L&P	Aux.
			CONSERVATION LEVEL I % of load saved				
New Construction	NE	115	30	25	5	15	20
	NC	115	33	25	5	15	20
	S	115	35	20	5	15	20
	W	115	38	17	5	15	20
Retrofit	NE	230	14	16	0	12	26
	NC	230	16	16	0	12	26
	S	230	13	9	0	11	20
	W	230	13	8	0	11	20
			CONSERVATION LEVEL II				
New Construction	NE	355	42	35	5	20	25
	NC	355	45	35	5	20	25
	S	355	48	35	5	20	25
	W	355	51	32	5	20	25
Retrofit	NE	590	21	26	0	30	33
	NC	590	24	26	0	30	33
	S	590	19	14	0	28	25
	W	590	22	12	0	28	25
			CONSERVATION LEVEL III				
New Construction	NE	880	50	41	10	20	30
	NC	880	53	41	10	20	30
	S	880	55	40	10	20	30
	W	880	58	37	10	20	30
Retrofit	NE	1,100	29	56	30	42	53
	NC	1,100	32	56	30	42	53
	S	1,100	30	28	30	39	40
	W	1,100	33	25	30	39	40

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: HOSPITAL

CONSERVATION LEVEL I

		First Cost $/1000 ft^2	% of load saved Heating	Cooling	Hot Water	L&P	Aux.
New Construction	NE	140	20	15	10	10	10
	NC	140	23	15	10	10	10
	S	140	20	20	10	10	10
	W	140	23	17	10	10	10
Retrofit	NE	280	7	7	12	8	19
	NC	280	9	7	12	18	19
	S	280	11	8	12	7	16

CONSERVATION LEVEL II

		First Cost $/1000 ft^2	Heating	Cooling	Hot Water	L&P	Aux.
New Construction	NE	455	32	25	15	15	15
	NC	455	35	25	15	15	15
	S	455	35	30	15	15	15
	W	455	38	27	15	15	15
Retrofit	NE	760	15	24	24	12	25
	NC	760	18	24	24	12	25
	S	760	23	13	24	10	22
	W	760	26	11	24	10	22

CONSERVATION LEVEL III

		First Cost $/1000 ft^2	Heating	Cooling	Hot Water	L&P	Aux.
New Construction	NE	1,040	40	33	20	15	15
	NC	1,040	43	33	20	15	15
	S	1,040	45	35	20	15	15
	W	1,040	48	32	20	15	15
Retrofit	NE	1,300	16	28	31	17	30
	NC	1,300	19	28	31	17	30
	S	1,300	23	15	31	14	27
	W	1,300	26	12	31	14	27

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: RETAIL STORE

		First Cost $/1000 ft^2	Heating	Cooling	Hot Water	L&P	Aux.
			CONSERVATION LEVEL I % of load saved				
New Construction	NE	80	30	25	0	15	10
	NC	80	32	25	0	15	10
	S	80	28	35	0	15	10
	W	80	30	32	0	15	10
Retrofit	NE	160	8	12	0	13	18
	NC	160	10	12	0	13	18
	S	160	11	7	0	12	12
	W	160	13	6	0	12	12
			CONSERVATION LEVEL II				
New Construction	NE	175	42	37	5	24	16
	NC	175	45	37	5	24	16
	S	175	45	40	5	24	16
	W	175	48	37	5	24	16
Retrofit	NE	290	23	20	0	25	36
	NC	290	26	20	0	25	36
	S	290	25	11	0	23	24
	W	290	27	10	0	23	24
			CONSERVATION LEVEL III				
New Construction	NE	420	50	46	10	30	20
	NC	420	53	46	10	30	20
	S	420	55	50	10	30	20
	W	420	58	45	10	30	20
Retrofit	NE	520	25	20	0	25	45
	NC	520	28	20	0	25	45
	S	520	29	13	0	23	30
	W	520	32	11	0	23	30

CONSERVATION TECHNOLOGY COSTS & SAVINGS

BUILDING TYPE: MISCELLANEOUS

		First Cost $/1000 ft^2	Heating	Cooling	Hot Water	L&P	Aux.
			CONSERVATION LEVEL I % of load saved				
New Construction	NE	150	30	25	5	15	15
	NC	150	33	25	5	15	15
	S	150	35	35	5	15	15
	W	150	38	32	5	15	15
Retrofit	NE	300	9	5	0	9	14
	NC	300	11	5	0	9	14
	S	300	8	4	0	8	13
	W	300	10	3	0	8	13
			CONSERVATION LEVEL II				
New Construction	NE	400	42	35	10	15	20
	NC	400	45	35	10	15	20
	S	400	42	42	10	15	20
	W	400	45	39	10	15	20
Retrofit	NE	660	15	12	0	15	23
	NC	660	18	12	0	15	23
	S	660	20	7	0	14	23
	W	660	23	6	0	14	23
			CONSERVATION LEVEL III				
New Construction	NE	1,040	50	40	10	20	20
	NC	1,040	53	40	10	20	20
	S	1,040	45	45	10	20	20
	W	1,040	48	42	10	20	20
Retrofit	NE	1,300	26	24	0	24	32
	NC	1,300	30	24	0	24	32
	S	1,300	40	13	0	22	31
	W	1,300	44	12	0	22	31

FIRST COSTS OF CONVENTIONAL HVAC EQUIPMENT

	Single Family $/unit	Low Density $/unit	Multi-Family $/unit	Mobile Homes $/unit	Office/Bank $/1000 ft^2	Retail $/1000 ft^2	Schools $/1000 ft^2	Hospitals $/1000 ft^2	Other $/1000 ft^2
A. Gas Heat									
NE	2,980	2,650	2,322	577	5,170	3,500	4,280	5,140	3,500
NC	3,073	2,750	2,412	599	5,360	3,640	4,430	5,320	3,640
S	2,730	2,410	2,115	528	4,720	3,200	3,920	4,700	3,200
W	3,073	2,750	2,412	600	5,360	3,650	4,430	5,330	3,650
B. Oil Heat									
NE	3,026	2,660	2,205	817	5,130	3,490	4,250	5,130	3,490
NC	3,120	2,760	2,376	848	5,320	3,630	4,400	5,310	3,630
S	2,777	2,320	2,088	748	4,680	3,190	3,890	4,690	3,190
W	3,120	2,760	2,385	850	5,320	3,650	4,400	5,320	3,640
C. Elec. Heat									
NE	2,808	2,770	2,367	504	5,240	3,557	4,060	5,180	3,557
NC	2,886	2,880	2,457	522	5,430	3,700	4,490	5,360	3,700
S	2,538	2,530	2,160	461	4,780	3,250	3,970	4,740	3,250
W	2,886	2,880	2,457	524	5,430	3,710	4,490	5,370	3,710
D. Gas Heat W/AC									
NE	4,705	3,239	3,780	1,978	8,940	5,940	7,720	14,667	5,940
NC	4,682	3,360	3,870	2,051	9,150	6,080	7,600	13,500	6,080
S	4,308	2,949	3,636	1,810	8,610	5,730	7,140	11,900	5,730
W	4,866	3,362	3,888	2,056	9,180	6,095	7,620	13,520	6,095
E. Oil Heat W/AC									
NE	4,751	3,249	3,663	2,218	8,900	5,930	7,690	14,657	5,930
NC	4,909	3,370	3,834	2,301	9,110	6,069	7,570	13,490	6,069
S	4,355	2,859	3,609	2,029	8,570	5,720	7,110	11,890	5,720
W	4,913	3,372	3,861	2,305	9,140	6,085	7,590	13,510	6,085
F. Elec. Heat W/AC									
NE	4,533	3,359	3,825	1,905	9,010	6,000	7,500	13,040	6,000
NC	4,675	3,490	3,915	1,976	9,220	6,140	7,660	13,540	6,140
S	4,136	3,069	3,681	1,743	8,670	5,780	7,190	11,940	5,780
W	4,679	3,492	3,933	1,980	9,250	6,170	7,680	13,560	6,170
G. Elec. Heat Pump									
NE	4,833	3,654	3,975	2,205	9,310	6,150	7,800	13,040	6,150
NC	5,125	3,790	4,065	2,276	9,520	6,290	7,960	13,840	6,290
S	4,436	3,219	3,831	2,143	8,970	5,930	7,490	12,390	5,930
W	5,129	3,642	4,083	2,280	9,550	6,320	7,980	13,860	6,320
H. Gas Heat Pump									
NE	6,725	4,965	5,255	2,735	11,810	7,850	10,345	18,680	7,850
NC	7,275	5,110	5,375	2,820	12,060	8,015	10,200	17,280	8,015
S	5,890	4,260	4,725	2,890	11,050	7,595	9,290	15,000	7,595
W	6,920	5,115	5,025	3,190	11,735	8,035	9,865	16,945	8,035