Regional Residential Energy Use Models#

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ABSTRACT

This paper describes the methods used and the assumptions made in developing a regional data base for each of the nine U.S. census divisions. The data are used to provide regional input to a comprehensive engineering-economic computer model to simulate energy use in the residential sector from 1970 to 2000. These regional models provide an analytical tool with which conservation policies, technologies, and strategies can be evaluated for their effects on residential energy use, fuel expenditures, and capital costs.

1. *Introduction*

This report describes the development of regional models to simulate energy use from 1970 through 2000 for each of the nine U.S. Bureau of the Census divisions, shown in Fig. 1. The structure of these models is identical to that of the national residential energy model developed at ORNL.[1,2] The major contribution of this study is to develop the regional data sets that replace the original national data set as inputs to the model. These data sets define the regional residential energy systems for 1970 and specify the boundary conditions (exogenous variables) from 1970 through 2000.

In addition to developing these data sets, the report compares predictions obtained with the regional models with historical data for the 1970-1974 period. Finally, the model is used to evaluate the energy and economic effects of several conservation programs implemented in the East South Central division.

As in the national model, the regional models deal with annual energy use for four fuels (electricity, gas, oil, other); eight end uses (space heating, water heating, refrigeration, food freezing, cooking, air conditioning, lighting, other); and three housing types (single-family, multi-family, mobile homes).

Figure 2 is a schematic diagram of our residential model.[1,2] The demographics submodel calculates stocks of occupied housing units by type for each year of the simulation as functions of population and per capita income. Based on calculations of household formation and retirements

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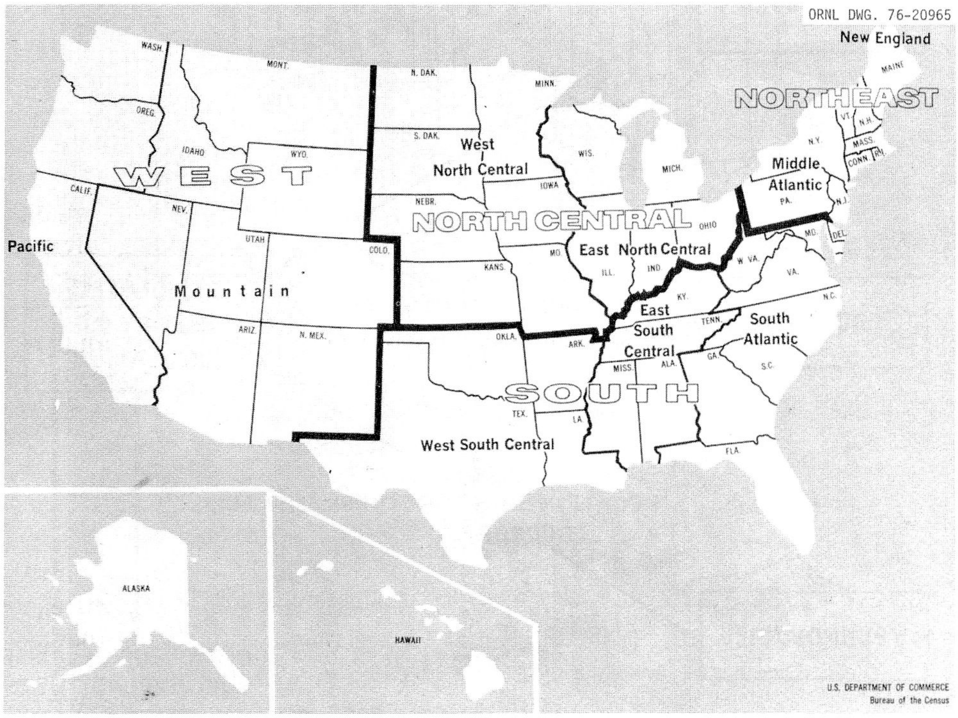

Fig. 1. Map of the United States showing Census divisions and regions.

from the existing stock of occupied housing units, new construction requirements are calculated for each year to insure that the stock of occupied housing units matches demand (the number of households that year).

Stocks of housing units and new construction in each region depend on regional retirement rates and the 1970 distribution of households by housing type in each region. Thus, the housing model is sensitive to both national and regional inputs in its calculations of households, housing choices, and new construction.

Unfortunately, housing choices are not now a function of housing prices. Also, the model cannot evaluate the effects of changes in household costs (e.g., energy costs) on household location or housing choices.

The economic submodels[3,4] calculate elasticities that determine the responsiveness of households to changes in economic variables: incomes, fuel prices, equipment prices. Elasticities are calculated for each of the three major household fuels for each of the eight end uses. Each fuel price and income elasticity is decomposed into two elements — an elas-

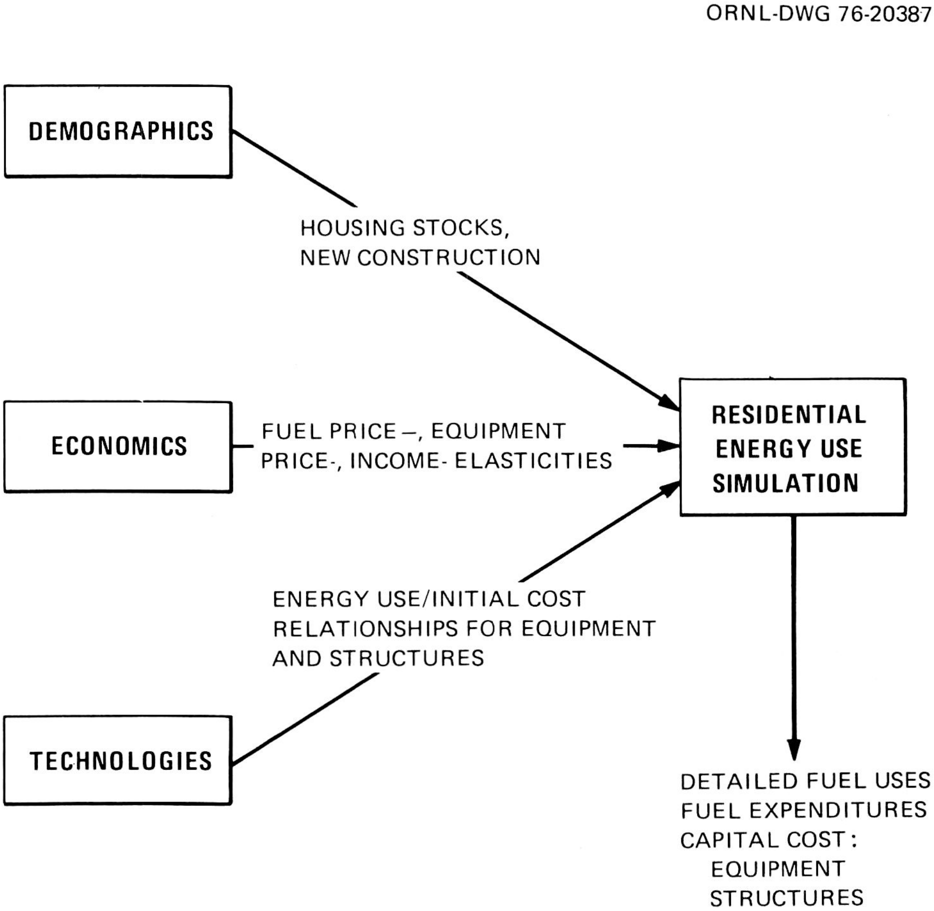

Fig. 2. Schematic of the ORNL residential energy use model.

ticity of equipment ownership (E_o) and an elasticity of equipment usage (E_u). The first gives changes in equipment ownership in response to changes in fuel prices, equipment prices and incomes. The second gives the responsiveness of equipment usage (with ownership held constant) to changes in own-fuel prices and incomes.

The technologies submodels[5,6] evaluate changes in equipment energy requirements and changes in equipment purchase price as functions of alternative designs. Detailed engineering submodels were constructed for gas and electric water heaters and for refrigerators. We synthesized data from a number of sources to infer relationships between equipment energy use and initial cost for the other end uses.

The simulation model combines outputs from the various submodels (Fig. 2) with appropriate initial conditions for 1970 and boundary conditions for the 1970-2000 period. Outputs from the simulation model include 96 fuel use components (Q_t^{ikm}) for each year (t): 4 fuels (i) x 8 end uses (k) x 3 housing types (m). The model also calculates annual fuel expenditures, equipment costs, and capital costs for improving thermal integrity of new and existing structures at the same level of detail. Each fuel use component is determined in the simulation program as the product of five factors:

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

where HT is the stock of occupied housing units, C is the fraction (market-share) of households with a particular type of equipment, TI is the thermal integrity 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.

Reference 1 contains a detailed description of the structure, inputs, validation, and operation of the ORNL residential energy use model.

The motivation for constructing regional models concerns the variations among regions in characteristics that influence residential energy use: population growth, housing choices, fuel prices and availabilities, income, climate, and fuel choices; see Table 1. For example, ownership of air conditioners is much lower in New England than in the West South Central division. Also, because of the warmer climate in the WSC division, the intensity of air conditioner usage (i.e., J/year) is much higher than in the NE division.

In the Middle Atlantic division, 45% of the households lived in multi-family units in 1970; in the East South Central division the comparable number was only 14%. Because space heating and air conditioning energy requirements are much smaller in multi-family than in single-family units, these differences in housing occupancy have major energy use effects.

TABLE 1. REGIONAL VARIATIONS IN RESIDENTIAL ENERGY USE DETERMINANTS, 1970

	High		Low	
Fuel prices (1970—$/$10^9$ J)				
Electricity	2.19	(MA)	1.59	(ESC)
Gas	1.78	(NE)	0.89	(MTN)
Oil	1.74	(ESC)	1.30	(NE)
Per capita income (1970—$)	4325	(PAC)	3263	(ESC)
Heating degree days	6631	(NE)	2075	(WSC)
Cooling degree days	2750	(WSC)	500	(MTN)
Equipment ownership market-shares (%)				
Air conditioners	61	(WSC)	18	(NE)
Electric space heating	20	(ESC)	3	(MA)
Percentage of households in single-family units	82	(ESC)	54	(MA)
Per capita fuel use (10^9J)	89.6	(ENC)	59.5	(PAC)

Incomes are important determinants of energy use. High-income areas are likely to have smaller households (and therefore more households per capita) than are poorer areas. High-income households are likely to own more energy-using household equipment and are likely to use such equipment more intensively than are low-income households.

The regional models developed here allow us to capture differences among divisions in the determinants of residential energy use. Variations in these factors cause significant differences in energy use. Per capita energy use varies by almost 50% among the regions (Table 1). In addition, these models enable us to evaluate the regional effects of national conservation policies and programs; and also evaluate the regional effects of regional programs.

2. *Historical Data for the Census Divisions*

To operate regional residential energy use models two types of input information are required (Table 2). The first includes initial conditions for 1970 that define the residential energy system in the Census division for that year. These data are discussed in this section. The second type of information required includes boundary conditions (exogenous variables) for the projection period. These inputs include population and income (which determine the number of households with the ORNL housing model[1,2]), fuel prices; and, to test the effects of various conservation programs, new equipment efficiencies and thermal integrities of new and existing residential structures. This second type of information is discussed in Section 3.

Residential fuel uses and prices are required to start the model in 1970. We also examine actual fuel consumption and prices for the 1970-1974

TABLE 2. INPUTS REQUIRED TO RUN REGIONAL RESIDENTIAL ENERGY USE MODELS

Initial conditions
1970 housing stock by type of unit
1970 fuel prices
1970 per capita income
1970 equipment ownership market-shares
1970 equipment fuel uses by fuel, end use, housing type
1970 aggregate fuel uses
1969/1970 fuel usage ratios
1970 new equipment market-shares
Boundary conditions (1970 - 2000)
population
fuel prices
per capita income
new equipment efficiencies
structure thermal integrities

period to test the predictive power of the regional models for this time period; see Section 4.

Residential consumption of electricity, gas, and oil are obtained from EEI,[7] AGA,[8] and the Bureau of Mines;[9] see Table 3. Corrections to these published figures are described in refs. 4 and 10. Electricity is treated in the models in terms of primary energy. That is, losses in generation, transmission and distribution are included; Table 3 shows the 1970 heat rate for each division. Losses in gas and oil conversion and transportation are not included.

Fuel prices for electricity, gas, and oil are obtained from statistics published by the Edison Electric Institute,[7] the American Gas Association,[8] the Department of Agriculture,[11] and McGraw Hill.[12] These prices are corrected to account for some fuel that is consumed in multi-family units but is classified as commercial.[4,10]

Estimates of state per capita income are from the Bureau of Economic Analysis (Department of Commerce).[13]

The per capita income and fuel price variables are adjusted for each year and state to account for temporal changes in price levels and regional variation in price levels. The Consumer Price Index (CPI),[14] published by the Bureau of Labor Statistics, is used as the temporal adjustment. Anderson's metropolitan cost-of-living index,[15] developed for 1970, is used to adjust for regional variations.

The number of households and the mix of housing types in each division for 1970 are obtained from the *1970 Census of Housing.*[16]

The regional models require input on equipment ownership market-shares by housing type (i.e., the fraction of households in housing type m that use fuel i for end use k). Data collected for the *1970 Census of Housing*[16] (available on the 1970 Public Use Sample tape) provides this information for space heating, water heating, cooking, freezing, and air

TABLE 3. RESIDENTIAL FUEL USES BY CENSUS DIVISION, 1970

	Fuel use (10^{18} J)					$\left(\frac{\text{J primary}}{\text{J electricity}}\right)^a$
	Electricity	Gas	Oil	Other	Total	
NE	0.280	0.153	0.577	0.021	1.031	3.57
MA	0.770	0.917	1.184	0.121	2.992	3.45
ENC	0.995	1.763	0.645	0.203	3.605	3.34
WNC	0.493	0.618	0.210	0.130	1.451	3.73
SA	1.050	0.415	0.514	0.159	2.138	3.44
ESC	0.507	0.259	0.030	0.117	0.913	3.10
WSC	0.627	0.522	0.003	0.080	1.232	3.49
MTN	0.211	0.281	0.034	0.041	0.567	3.32
PAC	0.721	0.730	0.090	0.037	1.578	3.11
U.S.	5.654	5.660	3.287	0.909	15.507	3.39

[a]To convert these overall heat rate values to British units, multiply by 3,412 Btu/kwhr.

conditioning. We assume that all households in all regions have electric refrigerators and electric lighting (i.e., 100% market-shares for both uses).*

The model also requires estimates of new equipment market-shares for 1970. Such information is not readily available. Therefore, we examined information from the Bureau of the Census[16,17] on equipment ownership market-shares for 1960, 1970, 1973, and 1974 and used these estimates to infer new equipment market-shares. The *Annual Housing Survey*[17] contains information on equipment ownership by fuel for each of the four Census regions (Fig. 1). Market-share estimates are not provided for the nine divisions. Therefore, we developed a simple ad hoc scheme to "create" equipment ownership estimates for the nine divisions based on the 1970 ownership patterns for the divisions[16] and the 1973 and 1974 ownership patterns for the regions.[17] The basic assumption used to derive these estimates is that the ratio of market-shares between two divisions within a region is the same in 1973 and 1974 as it was in 1970. Inputs to the program are market-share values for 1970 for each division, comparable values for the regions in 1973 and 1974, and the number of households in each division for 1973 and 1974. Estimated values of equipment ownership market-shares for each division for 1973 and 1974 are available from the second author.

As a check on the accuracy of this approximation method, we calculated the region's market-share for each fuel/end use combination based on the estimated division market-shares and compared this with the original estimate from the Bureau of the Census. The average deviation between estimated and actual regional market-share was 0.3%; the maximum discrepancy was less than 3%. This suggests that the estimation procedure is accurate.

Because the *Annual Housing Survey* provides information only for space heating, cooking, and air conditioning, we must look to other sources for the other end uses. For refrigeration and lighting, we assumed that the 1970 new equipment market-shares were the same across divisions: 1.08 and 1.02, respectively (see footnote on this page).

For water heating and food freezing, we examined Census data for 1960 and 1970[16] and estimates from the publication *Merchandising*.[18] Annual statistical issues of *Merchandising* contain estimates of equipment ownership market-shares for each Census division. Unfortunately, their estimates are not consistent with Census estimates for 1970, primarily because of problems associated with the small number of observations in their sample. Therefore, we estimated water heater and food freezer market-shares for 1973 and 1974 by linearly extrapolating Census estimates for 1960 and 1970. Fortunately, these extrapolated market-shares estimates from Census data agreed well with the regional estimates reported in *Merchandising* in terms of temporal trends.

*The simulation model sets the maximum market-share for refrigeration equal to 120% and the maximum market-share for lighting at 200% to allow for increases in ownership of these two types of equipment.

The final 1970 data set required to operate the regional models is fuel use by fuel, end use, housing type, and region. Dole[19] developed estimates of energy use by fuel and end use for each of the Census divisions for 1970. Dole's estimates explicitly account for climatic differences among regions that affect energy use for space heating and air conditioning. His numbers form the basis for our estimates of equipment energy use.

Dole's fuel use totals for each fuel and region do not exactly match the control totals developed for this study. Our electricity use figures are higher than Dole's because we convert electricity produced by falling water (hydropower) to primary energy at the heat rate applicable to steam-electric plants in each region (see Table 3). Dole converts hydropower electricity at 1 J/J. Our gas use estimates agree closely with Dole's. Our estimates of fuel oil use are 25% higher than Dole's. Finally, use of "other" fuels (coal, wood, liquified gases) for each division is obtained by assuming that the ratio of 1970 national use of other fuels estimated in refs. 2 and 10 to Dole's estimate applies to each division.

While Dole estimated energy use by end use and fuel type for each division, he did not examine differences in fuel use by housing type. For all end uses except heating, air conditioning, and lighting, we assume that differences across housing types are minor. For the three uses noted, we assume the relative energy use figures shown in Table 4.[1,2]

3. *Regional Boundary Conditions to the Year 2000*

The second set of inputs shown in Table 2 required to operate the regional residential energy use models is the exogenous variables for the 1970-2000 period. These variables include households and housing stocks (obtained from the ORNL housing model based on population and income inputs), fuel prices, per capita incomes, new equipment efficiencies, and thermal integrities for both new and existing residential structures. This section discusses development of the necessary inputs for households, incomes, and fuel prices. These inputs are derived for each division on the basis of assumed trajectories for the nation as a whole.

The ORNL housing model[1] produces projections for each division and year on number of households, distribution of occupied housing units by type of unit, and construction of new housing units by type. These regional projections are based on both national and regional inputs to the

TABLE 4. ESTIMATED ENERGY USE FOR EACH HOUSING TYPE RELATIVE TO SINGLE-FAMILY UNITS

	Size (m^2)	EU/EU_{SF}	
		lighting	space conditioning
Single-family	139	1.00	1.00
Multi-family	93	0.67	0.41
Mobile homes	67	0.48	0.61

housing model. The national inputs include population projections for each year by age group from the Bureau of the Census (Series II), assumed trajectory of per capita income, and an assumed distribution of occupied housing units by type and age for the year 2000. The regional inputs include projected shares of national population,[20] 1970 distribution of housing by type,[16] and assumed retirement rates for housing stocks;[21] all these inputs are from the Bureau of the Census.

The Departments of Commerce and Agriculture together develop projections of the economic activities for each state to the year 2000, known as the "OBERS Projections."[22] Reference 22 includes estimates of per capita income for 1970 and 1971 and projections for 1980, 1985, 1990, and 2000 for each state and for the U.S. We supplemented the historical estimates with data from the *Survey of Current Business* for the years 1970 through 1975.[13]

These historical data from 1970 to 1975 and projections to the year 2000 for per capita income were adjusted with Anderson's metropolitan-cost-of-living index.[15] The deflated state estimates of per capita income were aggregated to the Census division level, using the projected population of each state as the appropriate weight. This yields the ratio of per capita income in each division to that for the nation for each year to 2000.[13,22] These ratios (available from the second author) are then multiplied by the assumed trajectory of national per capita income to derive projected values of per capita income for each division.**

We next derive projections of fuel prices for each region from comparable projections of national fuel prices. We assume that growth rates in fuel prices for the nation apply to each of the Census divisions. Thus regional differences in fuel prices in 1974[4] (the latest year for which we have complete historical data) persist to the year 2000.

4. *Comparisons of Historical Data With Model Projections*

Model predictions of residential electricity, gas, oil, and total fuel use are compared with data for the 1970-1974 period. These comparisons are performed for each of the nine Census divisions.

Table 5 presents values of the mean square percentage error (MSPE)*** for each fuel and region for the 1971-1974 period. The initial year, 1970, is not included in the comparison because the initial conditions developed in Section 2 are defined so that model estimates of 1970 fuel use exactly match data. The MSPE values for electricity are quite low for all regions; the average is 3.1% and the highest is 5.0% for the PAC division.

**The OBERS projections of state income were prepared before the recent increases in fuel prices. It is possible that regional economic growth patterns will change because of these recent (and likely future) fuel price increases.

$$***\text{MSPE} = 100 \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{\text{Prediction}_i - \text{Data}_i}{\text{Data}_i}\right)^2}$$

TABLE 5. COMPARISONS OF REGIONAL RESIDENTIAL ENERGY USE PREDICTIONS AND DATA: 1971-1974

	Mean square percentage error (%)			
	Electricity	Gas	Oil	Total
NE	1.9	2.3	2.0	1.5
MA	2.9	5.2	1.1	2.6
ENC	2.5	6.7	3.1	3.6
WNC	4.2	6.6	3.7	4.0
SA	1.9	6.9	8.9	2.9
ESC	3.5	2.9	16.0	2.4
WSC	4.1	5.2	33.0	3.9
MTN	1.9	4.2	25.6	2.2
PAC	5.0	8.5	9.0	6.2

The accuracy with which the model predicts gas use is not as good. The average MSPE is 5.4% and the highest is 8.5% for the PAC division. The model overpredicts gas use in the later years in all regions, presumably because of increasing gas curtailments and shortages.****

Model predictions of oil use are quite good for those regions that use large quantities of oil (see Table 3): NE, MA, ENC, WNC, and SA. The average MSPE is 3.8% for these five divisions and the largest is 8.9% for the SA division. The predictions are poor for those regions that use very little oil. For example, the MSPE for the MTN division is almost 26%; however oil accounts for only 6% of the division's 1970 residential energy use. Thus, the discrepancies between actual and predicted oil use are inconsequential.

The last column of Table 5 compares model results and historical data for total residential fuel use in each division. The average MSPE is 3.3%; the highest is 6.2% for the PAC division. Fortunately, errors in predicting individual fuel uses tend to cancel each other.

The results of Table 5 suggest that the regional models accurately predict residential fuel uses and total fuel use for the limited test period. Because comparisons are performed for only four years, the results by themselves do not ensure that the models predict well. However, much more extensive tests performed with the national model[1] show that the (national) model provides close agreement with data on aggregate energy use, energy use by fuel, energy use by end use, and equipment ownership market-shares for the 1960-1975 period.

We also compared the sum of the regional projections with data on national residential energy use. The sum of the regional model outputs yields projections for the 1971-1974 period that are slightly more accurate than those obtained with the national model.[1] We do not view this improvement in predictive power as important, however, because the purpose of constructing regional models was not to develop better projec-

****To some extent, the 1970 initial conditions on new equipment market-shares capture the effects of constrained gas supplies.

tions of national energy use. Rather, the purpose was to develop tools to evaluate changes in regional energy use.

5. *Regional Projections: The East South Central Division*

As an example of the model's utility in analyzing the regional effects of alternative energy conservation strategies, we examine several conservation options in the East South Central Division. As Fig. 1 shows, the ESC Division includes Kentucky, Tennessee, Mississippi and Alabama.

We first developed a reference projection for the division in which we assumed that technical efficiencies for equipment and structures do *not* change between 1970 and 2000.***** The inputs concerning national trends in population, households, fuel prices, and per capita income are in refs. 1 and 23. The corresponding inputs for the ESC division are in Table 6. The reference projection produced with these inputs shows residential energy use growing from 1.01 x 10^{18} joules in 1975 to 1.09 x 10^{18} joules in 1980 and 1.57 x 10^{18} joules in 2000; see Fig. 3. The average growth rate in energy use from 1975 to 2000 for this projection is 1.8%/year. Electricity use grows more rapidly at 3.0%/year, while use of other fuels declines during this period.

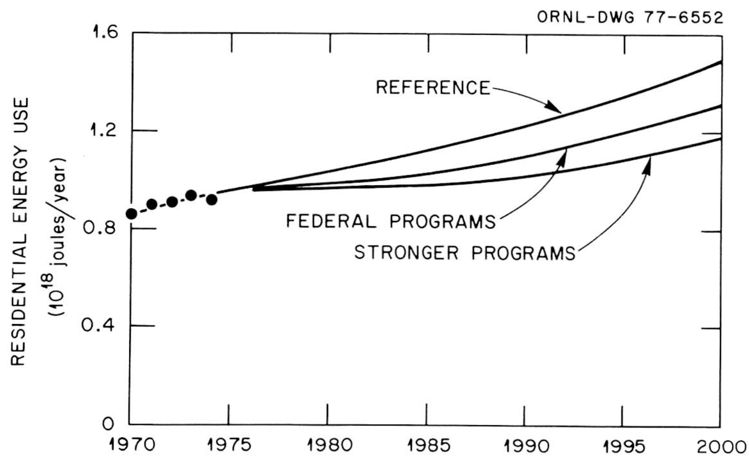

Fig. 3. Projections of residential energy use in the East South Central division.

*****We ignore the potential benefits of conservation research and development in the projections discussed here. That is, we do not allow implementation of advanced technologies such as solar or total energy systems.

TABLE 6. INPUTS USED IN PROJECTIONS OF RESIDENTIAL ENERGY USE IN THE EAST SOUTH CENTRAL DIVISION

	Population (10^6)	Households (10^6)	Fuel prices (1975—\$/10^9 J)			Per capita income (1975—\$)
			Electricity[a]	Gas	Oil	
1970	12.8	3.99	1.98	1.33	2.17	4,520
1975	13.0	4.33	2.22	1.54	3.52	5,110
1980	13.1	4.74	2.61	2.18	3.75	5,830
1985	13.5	5.17	2.99	2.82	3.99	6,690
1990	13.7	5.55	2.97	3.02	4.30	7,600
2000	14.4	6.18	2.91	3.40	4.88	9,860

[a]Recall that electricity is in terms of primary energy.

A comparable projection of national residential energy use shows an average annual growth rate of 2.2%.****** National growth is higher than projected growth in the ESC division (1.8%) because of higher growth in households for the nation (2.0%/year) than in the ESC division (1.4%/year). In fact, residential energy growth per household is higher in the ESC division than in the nation (0.4 and 0.2%/year, respectively).

The projected distribution of population across divisions[20] assumes that the gross migration trends from 1960 to 1970 continue. Thus, a declining fraction of the nation's population is projected to live in the ESC division. More recent projections than those in ref. 20 show a nearly constant fraction of the nation's population in the ESC division.

The national and ESC projections also differ with respect to fuel mix. Electricity's share of national household fuel use increases from 44% in 1975 to 70% in 2000. Electricity's share of the ESC division fuel use increases from 63% in 1975 to 85% in 2000. In both the nation and the ESC division, the shares accounted for by gas, oil, and other fuels all decline.

Implementation of FEA's appliance efficiency targets, the June 1974 HUD thermal standards for new residential construction, and a retrofit program that affects 1.3 million single-family units in the division between 1977 and 1990 is considered next. These three programs (discussed in ref. 23) might be implemented in response to federal legislation passed during the 94th U.S. Congress. However, the present administration's proposals (embodied in the April 1977 National Energy Plan) and the Congressional response to these proposals may result in different (probably stronger) conservation programs. We next ran our model for the ESC division using the inputs of Table 6 and the changes in efficiency implied by the three programs. These programs reduce residential energy

******Growth in residential energy use varies significantly across divisions. The MTN and WSC divisions have the highest growths: 3.2 and 3.0%/year, respectively. The MA and ESC divisions have the lowest growths: 1.4 and 1.8%/year, respectively. Thus, the average annual growth rate in energy use from 1975 to 2000 varies by more than a factor of two across Census divisions.

use in the division by 7% in 1985, 9% in 1990, and 12% in 2000; see Fig. 3. The cumulative energy savings (1977-2000) of 2.5 x 10^{18} J represents an 8% reduction in energy use. The net economic benefit to the region of implementing these programs totals $760 million (1975-$, present worth in 1977 @ a real interest rate of 10%). Table 7 summarizes the energy and economic effects of implementing these federal programs, both singly and in combination.

As a final example, we consider a much stronger conservation program for the ESC division. This program involves retrofitting more single-family units, retrofitting multi-family units, and making greater improvements in new equipment and structures than existing federal programs are likely to require. As Fig. 3 shows, the stronger program saves additional energy. As Table 8 shows, this program not only saves more energy, but it increases the economic benefits to the division. That is, the greater savings in fuel bills more than offset the increased capital costs of improved equipment structures.

6. *Summary*

A detailed data base for each of the nine U.S. Bureau of the Census divisions (Fig. 1) was developed to operate regional residential energy use models developed at ORNL.[1] These regional data sets include information on residential energy use and its determinants in 1970 for each

TABLE 7. CUMULATIVE (1977-2000) EFFECTS OF FEDERAL CONSERVATION PROGRAMS IN THE ESC DIVISION

		Cumulative direct economic effects	
	Cumulative energy savings (10^{18} J)	Benefit/cost[a]	Cost reduction (million $)
Appliances	1.7	1.4	410
New structures	0.5	2.2	230
Existing structures	0.4	2.3	220
Combined program	2.5	1.6	760

[a]The benefits are reduced fuel bills; the costs are for improved equipment and structures.

TABLE 8. THE ENERGY AND ECONOMIC EFFECTS OF FEDERAL AND STRONGER CONSERVATION PROGRAMS IN THE ESC DIVISION

	Federal programs	Stronger programs
Energy savings (10^{18}J)		
2000	0.2 (12%)	0.3 (21%)
1977-2000	2.5 (8%)	4.4 (14%)
Cumulative economic savings, 1977-2000 @ 10% (million $)	760	1700

division: housing stocks, equipment ownership, fuel prices, incomes, and fuel uses. In addition, information and methodologies are developed to provide boundary conditions for each division from 1970 through 2000 on households, fuel prices, and per capita incomes.

Although these models operate well and will be useful in conducting regional policy and program analyses, there are limitations with the models that should be addressed:

1. Fuel price and income elasticities. In constructing these regional models, we assumed that the fuel price and income elasticities used in the national model could be applied directly and without change to each division. A better approach would be to develop econometric models of household fuel use for each division.
2. Engineering relationships. In developing the national residential energy model (ref. 1), we derived estimates of the relationships between structure thermal integrity (i.e., seasonal heat loss or gain through the building shell) as a function of capital costs. These relationships are based on a typical home in the New York region (approximately 5,000 degree-days). Such relationships should be developed for each division because climate, construction practices, and costs vary from one division to another.

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