Changing Energy Use Futures, Proceedings of the Second International Conference on Energy Use Management, edited by R. A. Fazzolare and C. B. Smith, Pergamon Press, New York, 1979.

RESIDENTIAL ELECTRICITY DEMAND IN CALIFORNIA: RESULTS AND METHODOLOGY

Carl Blumstein
Energy and Environment Division, Lawrence Berkeley Laboratory
Berkeley, California

M. R. Jaske, T. Gorin, D. Carner, J. Carroll, S. George, B. Greene, L. Larson, D. Paige and S. Sarvate
Demand Assessment Office, California Energy Commission,*
Sacramento, California.

ABSTRACT

An end-use model of residential electricity sales has been developed for California and used to forecast sales to the year 2000 by major utility service area. Sales are disaggregated by 12 end-uses, 3 housing types, and 11 climate zones. End-use saturation estimates have been developed from analyses of data from the 1970 Census of Housing and from extensive surveys conducted by the California utilities in 1977. Unit energy consumption estimates have been derived using a variety of methods including computer calculations of space-conditioning loads, and statistical analysis of utility billing data combined with responses to saturation surveys. The detail provided by the model reveals interesting information about the structure of demand and permits examination of the impact of end-use specific energy conservation performance standards. Alternative scenarios are examined that consider variations in competing fuel prices, alternative economic/demographic growth paths, and possible new conservation initiatives.

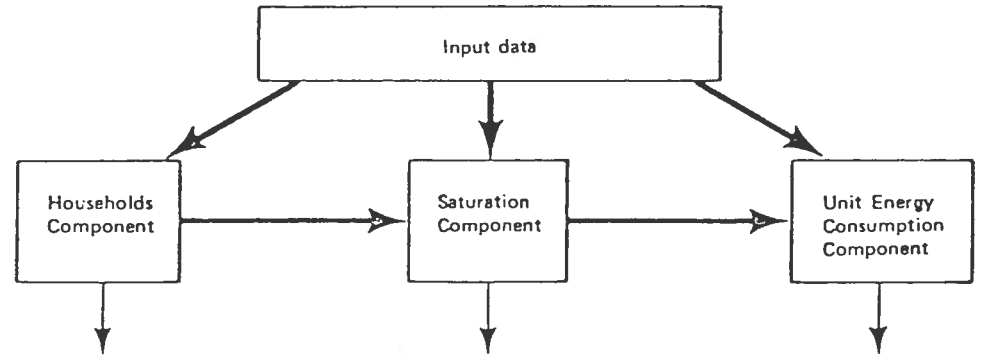
INTRODUCTION

The California Energy Commission (CEC) is required by the statute that established it to adopt forecasts of electricity sales to be used both for "a determination of need" in power plant siting and for the planning of programs in energy conservation and alternative energy development. This mix of objectives, satifying demand on the one hand and trying to moderate it on the other, placed some special requirements on the CEC's forecasting procedures. Not only is it necessary to assess future sales, but also to determine the likely impact of specific conservation policies such as appliance standards and changes in building codes. These requirements led the Commission to pioneer the application and advance the development of a new type electricity sales forecasting model -- the end-use model.

*This paper was prepared as the result of work sponsored by the California Energy Commission. It is the work product of individual staff members and has not been formally adopted or approved by the Energy Commission or the State of California.

The CEC adopted its first biennial forecast of electricity sales in 1977 (Ref. 1). An end-use model of residential sales was an integral part of this forecast, and thus, the Commission became the first public agency to commit itself to the end-use approach. The CEC was not the only pioneer of end-use models; similar developments were undertaken at Oak Ridge and Princeton (Refs. 2, 3). The success of these developments has been fairly convincing; the Federal Energy Information Administration has now adopted a residential end-use model and is making substantial investments to improve both the methodology and the data needed for end-use forecasting. Progress has also been made in developing end-use models for other sectors, particularly the commercial sector (Refs. 4, 5).

In August of this year, the CEC staff released its forecast for the second biennial report. (Ref. 6). The results obtained and the methods used in this forecast are the subject of this report as well as several others to be presented at this conference. Many of the conferees will be familar with the underlying structure of our subject, the residential end-use model. So, after a brief discussion of the basics, we will concentrate on what is new and different about this latest version and present some of the forecast results from our "base case" and some alternate scenarios.



$$\text{Electricity Sales} = \sum_i [HH_i \times \sum_j (S_{ij} \times UEC_{ij})]$$

THE MODEL

Conceptually, the residential end-use model is quite simple. As illustrated in Fig. 1, there are three basic components in the model. The households component provides forecasts of the number of households by housing type. The

saturation component provides forecasts of the number of energy consuming units (i.e., appliances and space conditioning equipment) per household. The unit energy consumption (UEC) component provides forecasts of the average electricity use per energy consuming unit. The electricity sales for each end-use are given by the product of households, the number of energy-consuming units per household, and the electricity use per unit. Total residential sales is simply the sum of the various end-uses.

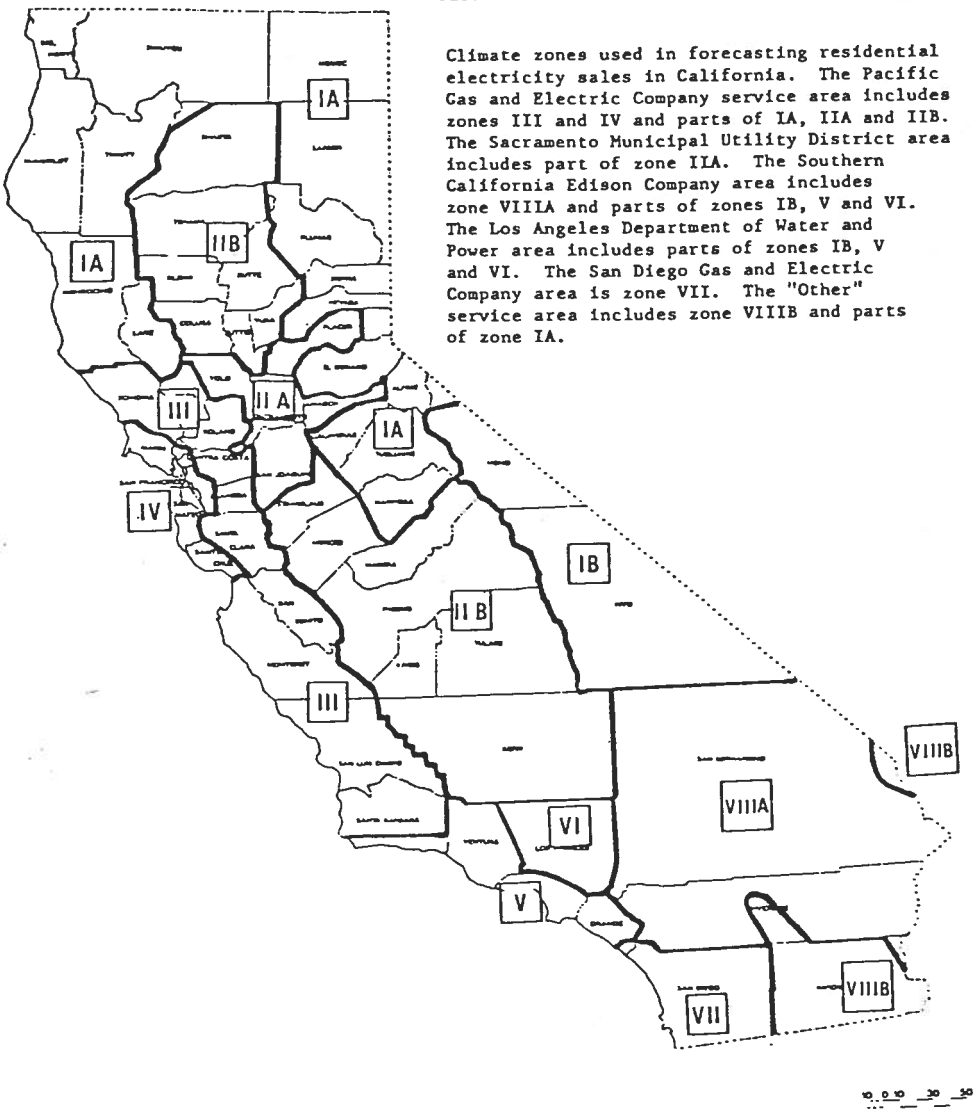
Unfortunately, the realization of this concept is not so simple. Foremost among the difficulties are very substantial requirements for data. Progress in satisfying these requirements is one of the significant features of the new forecast. A key to this progress has been the availability of surveys taken by the five major California utilities. These surveys, made in 1977 at the request of the CEC, obtained responses from more than 50,000 households on appliance holdings and household characteristics. The responses were paired with one year of monthly utility billing data. In addition, more effective use was made of some of the sources used in the first biennial forecast, particularly the Sixth Count of the 1970 Census of Housing.

The availability of data has made it possible to increase the level of detail in the model. Twelve end-uses are now forecasted: refrigeration, freezing, cooking, hot water heating, dishwashing, clothes washing, clothes drying, television, lighting and miscellaneous, space heating, air conditioning, and pumping for swimming pool filters and sweeps. For many of these end-uses, alternative fuels and/or equipment types are also forecasted (e.g. evaporative, room, electric central, and gas central air conditioners). All of the end-uses except pools are disaggregated by housing type (single family, multi-family, and mobile home). The model makes forecasts for six utility service areas, the five major utilities [Pacific Gas and Electric (PG&E), Southern California Edison (SCE) Sacramento Municipal Utility District (SMUD), Los Angeles Department of Water and Power (LADWP), and San Diego Gas and Electric (SDG&E)] and "other". Since the saturation and energy requirements for space conditioning equipment are very dependent on climate, the space conditioning end-uses are further disaggregated into climate zones. Eleven zones have been used to describe the California climate (see Fig. 2). The overlay of these zones on the service areas produces fifteen forecast areas.

The Household Component

The households component makes forecasts by housing type of the number of households, the average number of persons per household, and new construction in each of the 15 forecast areas. The basis of these forecasts are the California Department of Finance (DOF) estimates of population by county in 1978 (Ref. 7) and their forecast of households and persons per household by county for the E-150 population series (Ref. 8). New construction is determined by the number of units required to accommodate the growth in households and to replace units that are removed or converted. The rate of removal or conversion is estimated from the 1970 Census of Housing Components of Inventory Change. Housing types in new construction are assumed to be the same as the average of the past nine years (Refs. 9, 10). Persons per household by housing type in 1977 is determined from the utility surveys. For the forecasts, persons per household in multi-family and mobile units are assumed to remain constant and the persons per household in single family units are adjusted to make the overall average persons per household consistent with the projections in the Department of Finance household forecast.

FIGURE 2



Climate zones used in forecasting residential electricity sales in California. The Pacific Gas and Electric Company service area includes zones III and IV and parts of IA, IIA and IIB. The Sacramento Municipal Utility District area includes part of zone IIA. The Southern California Edison Company area includes zone VIIIA and parts of zones IB, V and VI. The Los Angeles Department of Water and Power area includes parts of zones IB, V and VI. The San Diego Gas and Electric Company area is zone VII. The "Other" service area includes zone VIIIB and parts of zone IA.

The Saturation Component

The saturation component forecasts the saturation of end-use equipment by housing type for different equipment types and fuel choices. Most of the forecasts are based on a model proposed and developed by Dole (Ref. 11) using data from the 1970 Census of Housing and the utility surveys. However, some significant changes were made in the model of fuel choice for space heating, water heating, and cooking (see Ref. 12 for details).

Among the reasons for making changes in the fuel choice model was a desire to include the effects of fuel availability. In California, one of the most important factors in influencing the use of resistance space and water heat is the availability of natural gas. In addition, the new California building

code prohibits the use of resistance heat where it is not cost effective, and cost-effectiveness is greatly affected by gas availability. Gas availability is also a decisive factor in determining the economic attractiveness of solar water heating, which is cost-effective in all areas when compared to electricity, and therefore, effectively mandated by the Title 24 Building Code in areas without natural gas.

Surprisingly, even the gas utilities do not have a good knowledge of the fraction of households within their franchises that do not have gas available (i.e., are too far from a gas main to obtain service at a reasonable cost). Consequently, it was necessary to devise a procedure for estimating this fraction for each of the forecast areas. The starting point for these estimates was an examination of fuel choice in counties where there is no natural gas service. Table 1 gives the saturations of electric space and water heating in these counties in 1970. Although there is considerable variability among the counties, the table does give an indication of the householder's fuel choice decision when the alternatives are electricity and fuels other than natural gas. If we assume that the householder will not choose "other" (usually LPG) when natural gas is available and that fuel choice behavior in other areas without natural gas is represented by the averages of the counties in Table 1, then we can obtain estimates of gas availability in the rest of the state by two approaches. For example, the assumptions imply that "other" fuel is used for space heating in about 70 percent of the homes where natural gas is not available. Since we know how many homes use "other" fuel for space heating and we have assumed that these homes are all in areas where natural gas is not

TABLE 1 ELECTRIC SPACE AND WATER HEAT IN CALIFORNIA COUNTIES WITHOUT NATURAL GAS[a]

County	All Occupied Units	Units With Electric Space Heat	Percent Electric Space Heat	Units With Electric Water Heat	Percent Electric Water Heat
Alpine	128	-	-0-	67	52.3
Del Norte	4778	1703	35.6	3563	74.6
Inyo	5571	744	13.4	2019	36.2
Lake	7546	2875	38.1	4802	63.6
Lassen	5127	1048	20.4	3308	64.5
Mareposa	2126	397	18.7	1150	54.1
Modoc	2641	843	31.9	2182	82.6
Mono	1300	286	22.0	442	34.0
Plumas	4389	863	19.7	2843	64.8
Sierra	831	107	12.9	528	63.5
Siskiyou	11326	2906	25.7	8652	76.4
Tuolumne	7432	2462	33.1	3818	51.4
	53195	14234	26.8	33374	62.7

[a]Source: 1970 Census of Housing

available, we can estimate the number of homes where natural gas is not available by multiplying the number of homes using other fuel for space heat by 1.4. A similar estimate can be developed using water heater data. It may be generous to call this procedure "rough and ready", but the two estimates agree reasonably well in most of the forecast areas. According to this method of estimation only about 7 percent of California's households do not have natural gas available. But roughly 17 percent and 30 percent of the state's electric space and water heat, respectively, are concentrated in these households.

The Unit Energy Consumption (UEC) Component

The UEC component estimates the average energy consumption of individual end-use units. These estimates are made by housing type and, for the space-conditioning end-uses, by climate zone. This component of the model received the most attention in the preparation of the forecast but, since the methods that were used are the subject of other papers at this conference, we will be brief in our discussion of this work. Probably the most significant advance was the development and use of statistical methods for estimating UECs from utility billing data combined with responses from the saturation surveys. By these methods not only were we able to make estimates for the UECs of end-uses that are hard to obtain by other methods (especially, lighting and miscellaneous) but also to derive estimates of electricity-price, household-size, and income elasticities for some end-uses. A variety of engineering calculations were used to supplement the statistical methods (especially to estimate the impact of new energy performance standards). In particular, the heat load modeling computer program DOE 1.4 was used extensively to calculate space-conditioning loads as a function of house size, climate, insulation level, etc.

Reconstructing Electricity Sales with the Model

How well does all of this work? One obvious test is to use the model to reconstruct residential electricity sales in past years. Table 2 compares the results of such a reconstruction with the reported sales for each of the six service territories and the state as a whole for the years 1976 - 1978. Results for the state as a whole are quite good with the difference between reported and modeled values averaging 4.5 percent. The worst results are for "other", a collection of small rural utilities. These utilities were not included in the 1977 saturation surveys so the end-use saturations used in the model are less accurate than for the other territories. It is possible that some of the difference between the model and the reported sales is due to misclassification of sales in some of the reports. In 1975 the major utilities began reporting sales on an SIC code basis as well as a rate schedule basis. In territories where master metering of apartments has been widespread, such as LADWP, the conversion to SIC coding has been difficult and under-reporting may persist.

Of course, even perfect agreement between the model and reported sales would not guarantee the accuracy of the forecast results. In addition to the data required for reconstruction of past sales, the forecast depends on assumptions about future trends in a number of factors including prices, consumer behavior, government policy, technology, and population growth.

RESULTS

The forecast result that has received the most attention is, of course, the bottom line. Table 3 summarizes the base-case forecast results for the six service territories and the state as a whole. The results are significantly

lower than previous forecasts as well as recent history. The statewide growth rate for the period 1978 to 2000 is about half the rate forecast in the first Biennial Report. It implies that energy consumption per household will be essentially constant during the forecast period.

TABLE 2 RECONSTRUCTION OF RESIDENTIAL ELECTRICITY SALES WITH THE CEC END-USE MODEL (Billions of kWh)

	PG&E	SMUD	SCE	LADWP	SDG&E	OTHER	STATE
1976							
Reported	19200	2200	15100	5500	3400	1000	46300
Modeled	19800	2100	15500	6000	3400	900	47700
% Difference*	3.4	-1.5	3.0	8.9	-0.3	-15.9	3.3
1977							
Reported	19100	2300	15500	5700	3500	1100	47200
Modeled	20500	2300	16300	6000	3600	1000	49700
% Difference*	7.4	1.5	5.3	4.9	0.5	-12.6	5.3
1978							
Reported	20200	2500	16400	6000	3800	1200	50100
Modeled	21700	2400	17100	6200	3800	1100	52300
% Difference*	7.4	-3.9	4.7	3.2	-1.9	-8.7	4.8
Three-Year Average							
% Difference	6.1	-1.3	4.3	5.6	-0.6	-12.4	4.5

*Percentage difference computed from unrounded figures.

TABLE 3 GROWTH RATES FOR RESIDENTIAL ELECTRICITY SALES--- BASE CASE FORECAST

YEAR	PG&E	SCE	SMUD	LADWP	SDG&E	OTHER	STATE
1970-1977	4.79	3.97[a]	6.42	1.06	7.22	N/A	4.52[b]
1978-1984	2.07	2.09	3.60	0.89	2.23	3.28	2.06
1978-1990	1.86	1.95	2.74	1.13	2.16	2.71	1.90
1978-2000	1.93	2.09	2.36	1.47	2.32	2.50	2.00

[a]Growth from 1970 to 1976

[b]Growth from 1970 to 1976, does not include Other

To understand this result it is necessary to examine the individual end-use forecasts. Table 4 shows the end-use results from the model for SDG&E and SMUD which account for about one sixth of the state's residential sales. These end-use proportions are reasonably reflective of the statewide pattern of residential sales. They indicate that electricity used for water heating is quite low and declining in the future. Electricity used for space heating is low but growing in the future due to its use in multi-family housing. This results from the very heavy dependence of California residences for natural gas to operate these end-uses, and the cost-effectiveness regulations which will futher accentuate this pattern. Refrigeration, lighting and miscellaneous, and space heating constititute the three single largest uses. Air conditioning growth, although moderated by the relatively stringent CEC efficiency standards, continues as it has done for the recent past. It is precisely this factor that has caused each of the five major California utilities to become summer peaking utilities. As revealed by Table 4, an end-use forecast can offer substantial information about customer demands and for governments attempting to control the use of scarce resources.

TABLE 4 COMPONENTS OF RESIDENTIAL CONSUMPTION FOR SELECTED SERVICE AREAS - 1977 and 2000 (%)

	SDG&E		SMUD	
	1977	2000	1977	2000
Refrigerators	24.1	26.0	15.7	14.2
Freezers	5.2	5.1	5.7	5.8
Cooking	5.3	8.0	4.5	4.6
Television	7.3	5.7	4.5	3.0
Dishwasher	2.9	4.1	2.3	2.3
Clothes Washer	1.7	1.2	1.5	0.9
Water Heat	8.8	3.4	8.9	3.1
Solar Backup	0.1	0.3	0.0	0.1
Space Heat	8.8	9.8	10.7	26.1
Central A/C	1.3	1.6	13.5	10.9
Room A/C	0.7	1.0	2.0	0.4
Evaporative Coolers	0.1	0.1	0.4	0.3
Clothes Dryers	5.5	4.7	6.6	4.9
Swimming Pools	4.6	6.2	2.5	2.5
Lighting & Misc.	23.6	22.8	21.2	20.9
	100.0	100.0	100.0	100.0

To examine the effects of changes in the assumptions used for the base case, six alternative scenarios were developed. The scenarios examined high and low growth rates in the number of households, high and low energy prices predicated on oil price behavior and very vigorous and lax conservation efforts. The high and low household forecasts use DOF's series D-225 and F-75 population forecasts and assume that the number of person per household will be the same as in the DOF household forecast for the E-150 series. This gives growth rates in the number of households for the period 1978 - 2000 of 1.9 percent and 1.3 percent as compared to 1.7 percent in the base case. In the high and low price scenarios real electricity prices grow at rates of 1.4 percent and 0.6 percent as compared with 1.1 percent in the base case. In the high conservation scenario new standards increase the efficiency of refrigerators, freezers, and air conditioners by an average of about 20 percent, retrofit insulation reaches all dwellings where it is technically feasible, and the CEC's load management programs are adopted by a majority of households by 1995. In the low conservation scenario standards adopted after 1975 are not enforced and no new conservation initiatives are undertaken. The results of these scenarios for statewide electricity sales are given in Table 5 and illustrated in Fig. 3.

It is clear from examination of Table 5 and Figure 3 that high/low price and high/low population scenarios do not diverage materially from the baseline. The high/low conservation scenarios exhibit a wider range of variation. Even the low conservation scenario (the single most divergent attribute) does not produce a forecast growth rate in the range shown in Table 3 for the 1970-1977 period. Combination of scenario attributes would result in wider departures from the baseline than the single attribute scenarios described here. The ability to produce a forecast predicated upon alternative assumptions is an important modeling characteristics for a policy determining body such as the CEC.

FURTHER WORK

The residential sales forecast produced by the CEC through July 1979 and summarized here will undergo intensive scrutiny during the formal adoption procedures yet to come. The criticisms raised will guide future efforts at improving the methodology of the forecasting model and the data which it requires. Several areas seem to require further work in light of current knowledge about residential sales. Among these are the following: behavioral differences in appliance choice and operating patterns along income and family size dimensions, the cost-effectiveness regulation's dependence upon equipment costs and operating expenses for space and water heating, and imprecision of reported sales by customer types. Future efforts also include work to make the computer programs that implement the model discussed here more efficient and convenient to use. This effort will culminate with detailed operating manuals and release of the computer code to facilitate public access to the methodology.

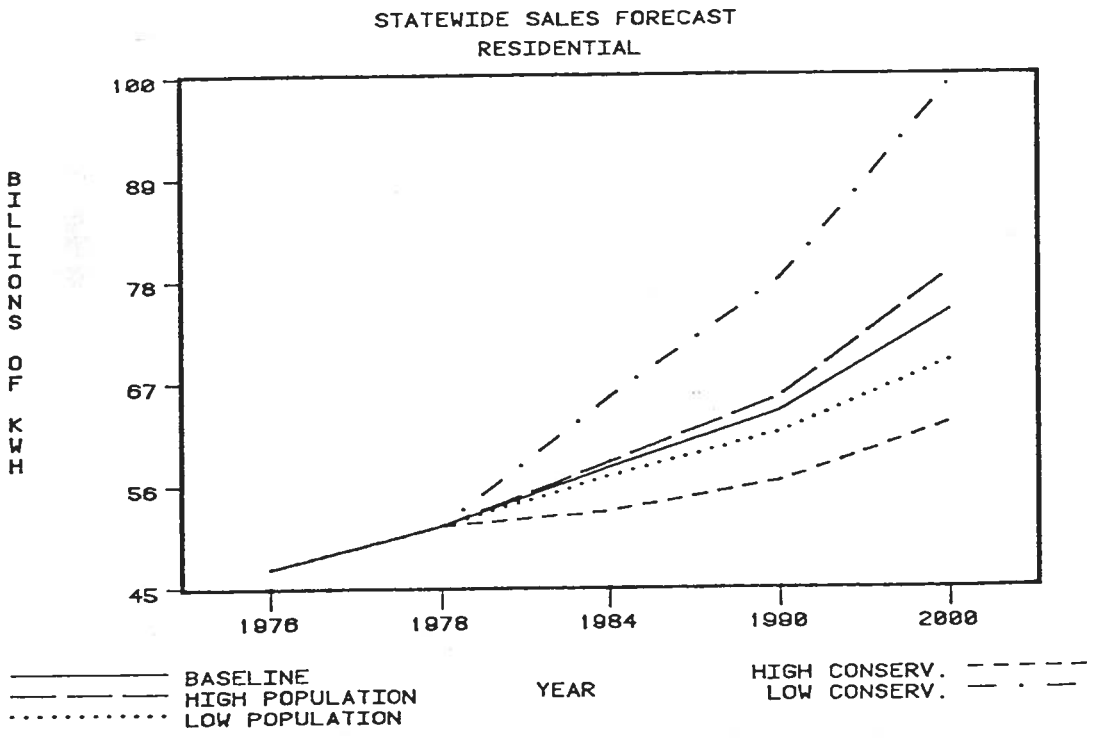
ACKNOWLEDGEMENT

The authors wish to acknowledge the invaluable assistance of the clerical and statistical staff of the Demand Assessment Office as well as that of the Word Processing Center in preparation of this work.

TABLE 5 ALTERNATIVE SCENARIOS FOR THE GROWTH OF RESIDENTIAL ELECTRICITY SALES BY SERVICE AREA (Percent per Year)

	PG&E	SMUD	SCE	LADWP	SDG&E	OTHER	STATE
Baseline	1.93	2.36	2.09	1.47	2.32	2.50	2.00
High Price	1.85	2.24	1.85	1.35	2.15	2.39	1.85
Low Prices	2.02	2.39	2.28	1.70	2.46	2.52	2.13
High Population	2.20	2.04	2.33	1.67	2.55	2.74	2.17
Low Population	1.64	1.51	1.74	1.11	1.98	1.90	1.61
High Conservation	1.14	1.61	1.40	0.56	1.53	1.68	1.23
Low Conservation	3.02	3.56	3.52	2.21	3.54	2.83	3.17

FIGURE 3



REFERENCES

1. California Energy Commission, 1977 Biennial Report to the Legislature, Volume 2.

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

3. Weatherwax, R. K. and R. Williams, Energy Conservation/Load Management Analysis for the Residential, Small Commercial, and Industrial Sectors of the Consolidated Edison Electric Franchise District, Center for Environmental Studies, Princeton University, unpublished manuscript, March 1977.

4. Jackson, Jerry, et al., "The Commercial Demand for Energy: A Disaggregated Approach", ORNL/CON-15, 1978.

5. California Energy Commission, Natural Gas Supply and Demand for California: Staff Report, Appendix A, May 1978.

6. California Energy Commission, California Energy Demand Forecast: 1978 to 2000, August 1979.

7. California Department of Finance, Population Forecasts for California Counties, Publication P-3, December 1977.

8. California Department of Finance, Series E-150 Population and Households Forecast to 2000, private communication from Isabel Hambright.

9. Security Pacific Bank, California Construction Trends, December issues for 1970 - 1978.

10. Mobile Home Market Research, Inc., California Mobile Home Report, 1976, 1977 volumes.

11. Stephen H. Dole, Energy Use and Conservation in the Residential Sector: A Regional Analysis, Rand Report R-1641-NSF, June 1975.

12. California Energy Commission, 2nd Biennial Report: Technical Documentation of the Residential Sales Model, in preparation.