# ENERGY EFFICIENCY IN CALIFORNIA:
# A HISTORICAL ANALYSIS

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**July, 1995**

**Prepared for the California Energy Commission**



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## ACKNOWLEDGMENTS

We wish to thank our project managers at the California Energy Commission (CEC), Monica Rudman and Richard Rohrer, as well as John Wilson of Commissioner Imbrecht's office. Michael Messenger of CEC provided valuable comments on the manuscript, and Dale Trenschel and Gordon Schremp of CEC provided important CEC energy balances on diskette. Ken Boeke and Richard Rohrer, also of CEC, provided essential data.

Setiwan Wynardi assisted us in finding transportation data, while Luk Lee and Herbert Jew of Caltrans provided many of their own data and calculations. Laurel Clark of Caltrans found many old but important documents in the Caltrans Library.

We thank William Golove, Mike Ting, Marta Khrusuch, and Lynn Scholl from Lawrence Berkeley Laboratory as well as Brent Haddad from the Energy and Resources Group, University of California for their help with individual sectoral data. We also acknowledge assistance from the Federal Aviation Administration, the National Railroad Administration, the U.S. Department of Transportation, and the California Public Utilities Commission (CPUC) in providing data on regulated transportation common carriers.

Special thanks go to two staffmembers of the American Council for an Energy-Efficient Economy: Renee Nida for editing this report and Howard Geller for reviewing it.

## EXECUTIVE SUMMARY

California is one of the world's top ten consumers of primary energy. Understanding the nature and evolution of energy use and energy intensity is of great interest because of the links between energy, the economy, and the environment. Also, many steps have been taken by the state, by utilities, and by other organizations to increase energy efficiency in California during the past 20 years. However, there has been very little in-depth analysis of statewide energy efficiency or energy intensity trends and how such trends compare to those for the United States as a whole.

This study analyzes energy intensity and efficiency trends in California by sector (residential, service, manufacturing, and transportation). Wherever possible, we use data supplied by California state agencies, such as the California Air Resources Board, Caltrans, and the California Energy Commission. In the manufacturing sector, we use data from federal agencies such as the U.S. Census of Manufacturing. Once assembled, the data are analyzed to create a picture of the structure and intensity of energy use in California and how these factors have changed over time. To the degree possible, California energy intensity values and trends are compared to those for the entire nation.

In the residential sector, final energy demand per household in California declined 27% during 1970-93. Declining energy intensity was due to both structural effects (e.g., shifts in fuel shares and falling occupancy levels) and efficiency effects (e.g., improvements in appliance efficiency and building thermal integrity). It appears that policies such as building codes, appliance standards, and utility DSM programs helped to reduce residential energy use. California residences consume less energy than typical U.S residences, due in large part to structural factors such as less floor area per household, greater reliance on natural gas, and the significantly milder heating season compared to the national average. While California heating intensity (in energy/square meter/degree day) was higher than for the U.S. as a whole in 1975, the gap was narrowed by 1990. For appliances, changes in appliance unit consumption over time, resulting from turnover of the stock, indicate faster decline in unit energy consumptions than for the U.S. as a whole.

In the service sector, electricity use per unit of floor area increased 5% and gas use decreased 26% during 1975-91. In general, most building types show a decrease in energy intensity, with office buildings being the only exception. In offices, electricity consumed by office equipment and air conditioning has increased. While California's service sector is increasing both in absolute terms and as a share of the total U.S. service sector, California's share of national energy use in the service sector has been shrinking over time. Significantly lower service sector energy intensities in California compared to the U.S. are attributed to climatic differences, greater electrification, and policies such as building standards and utility DSM programs.

Manufacturing sector energy intensity is measured as the ratio of energy consumed to value added. Using this measure, California's manufacturing sector energy intensity fell

about 32% during 1978-90. The energy intensity reduction due to so-called efficiency improvements was about 22% and the reduction due to shifts in the mix of materials and goods produced was about 10%. Manufacturing energy intensity tends to be lower in California than in the U.S. as a whole. This is due in part to differences in product mix -- energy-intensive manufacturing represents only about 10% of total output in California compared to about 22% for the nation. However, manufacturing energy intensity is lower in California than for the nation as whole when comparing within individual industry categories. This may be due to differences in product mixes within industry categories, as well as differences in energy prices or technology choices.

Transportation of all types accounts for 40-45% of California's total final energy use, a large fraction in part because of relatively low energy use in other sectors. Also, transportation energy use in California is boosted by a high level of interstate and international air, marine, and truck travel. Transport energy use per capita in California declined about 10% during 1978-92. The average on-road fuel economy of cars and light trucks increased from about 14 MPG in 1980 to 21.5 MPG in 1992, similar to national trends, although California's passenger cars appear to be slightly more energy more energy-efficient than typical cars nationwide. Per capita fuel use for cars and light trucks is actually lower in California than for the U.S. as a whole, while that for heavy trucks is about the same. Contrary to popular belief, Californians appear to be less dependent upon automobiles than Americans in other states. When this energy is removed from the comparison, California's per capita energy for travel appears close to the national average. Use for freight could not be compared directly to that for the U.S.

In summary, final energy use per unit of economic output fell 28% in California during 1978-90. About one-third of this decline is due to structural changes and about two-thirds is due to reductions in actual energy intensities. Energy use per capita or per unit of economic output is about 30% lower in California than in the nation as a whole. In this case, about two-thirds of the difference is due to structural and climate effects; about one-third is due to lower energy intensities (including higher energy efficiencies) in California. Finally, it appears that energy intensities fell somewhat faster in California than in the U.S. as a whole during 1978-90. While it is difficult to determine what caused these trends, it appears that both energy prices and state policies played a role.

# 1. INTRODUCTION

In addition to increasing energy prices, since the 1970s, Californians have been facing appliance standards designed to restrict sales of energy-using equipment to more efficient designs, and building codes to decrease the energy intensity for space heating and cooling in households. California's utility programs have included information, rebates, and low-interest loans to consumers.

This report provides a new perspective on the efficiency of energy consumption in California through (1) a thorough historical analysis of the structure and intensity of energy demand in California, (2) comparison of that structure and intensity with those of the United States, and (3) analysis, in light of these findings, of developments in energy use since the 1970s, including an estimate of how much energy has been saved since that time. Our time frame is 1970-1991 for the residential and service (commercial) sectors, but because of critical data problems, 1978 or 1980 to 1991 for manufacturing and travel-related transportation. In all, we have adequate data to analyze 80% of the final (site) energy use in California, but data for freight and industry except manufacturing (mining, construction, utilities, agriculture) are too sparse or non-existent.

## 1.1. More About This Project

Understanding the nature of energy efficiency and its evolution in countries or states is important due to concerns regarding the links between energy use and environment, as well as the equally important links between energy use and the economy. Yet we have little knowledge of how intensively energy is used in California.[2] References to the relatively low ratio of primary energy use to Gross State Product (GSP) (or population) in California offer no proof or even indication of how efficiently Californians use energy.

To understand how California uses energy, we have to examine how individual energy uses (space heating, cooling, truck transportation, production of various commodities, etc.) are related to the activities or output for which energy is used. This requires a far greater analysis of the structure of activity in California than ever before attempted by the California Energy Commission; however, many other public and private authorities (such as Caltrans, the California Air Resources Board [CARB], the California Department of Finance, individual electric and gas utilities, the California Public Utilities

[2] In this report we use the terms "energy efficiency" and "energy productivity" interchangeably to denote the factor productivity of energy, i.e., output per unit of energy input, other inputs held constant. We use "intensity" to denote a disaggregated measure of energy use per unit of activity. See further explanation of terms in Section 1.5.1.

Commission, automobile companies, etc.) do follow the evolution of individual sectors of activity.

Combining information on energy use with data on the structure of these activities permits us to form indicators of energy productivity (or its near-inverse, energy intensity). Using previous research carried out at the Lawrence Berkeley Laboratory, we illustrate what can be learned from these kinds of energy indicators. We then apply these indicators to California. Additionally we assemble certain indicators of the energy efficiencies of new systems--appliances, cars, etc. sold in California, or properties of homes and buildings constructed here. Many of these indicators are compared with those from the U.S. or even from other countries.

We demonstrate that a great deal is known about the structure and efficiency of residential and commercial (service) sector energy use, both from actual measurement and from models. But surprisingly little is known about the manufacturing sector, the last complete data for which were assembled by the *Annual Survey of Manufacturers* (ASM) in 1981 (!). And while the total use of transportation fuels in California is well known, the accurate breakdown between cars, trucks, busses, electric transit, rail, and other modes is not well known. Worse, we do not know the levels of activity (in passenger miles or ton miles) for which these modes use energy.

In this study, we will show what we do know about California, what we can learn by tapping into existing data streams, and what we can only learn by putting pressure on local, state, or federal authorities (public and private) to expand their on-going data collection and analysis efforts to provide state-level information. In some cases we give relatively precise figures to describe important findings, trends, and differences between California and the U.S. In many cases, however, we denote findings with "greater/less" or "growing/declining." We do this when we feel the overall difference or trend is clear but difficult to quantify.

## 1.2. Why Care About Energy In California? The Debate over Energy in the Economy

There is clear concern about energy among public and private authorities world-wide (see Schipper 1993). While concern over the risks of importing oil may have faded in some quarters, worries over the environmental effects of using energy, including those related to emissions of carbon dioxide ($CO_2$) and other gases, continue to make energy production and consumption a focus of public policy. There is particular concern in California over transportation, both traffic per se and fuel consumed (which results in significant air pollution), and this focuses attention on petroleum use.

Primary energy consumption in California approached 8 EJ (8 Quads) in 1992, putting California among the top ten energy consuming "states" in the world, just behind France as number 8. Yet there has been very little systematic analysis of patterns of energy use in the state, most work focusing on energy supply (Borg and Briggs 1994) or aggregate comparisons of energy use (see for example Lenssen and Flavin 1994).[3] CEC models and analyses provided to the authors examine individual sectors, but the CEC *Energy Efficiency Reports* do not integrate sectoral and subsectoral analyses into a picture of the entire state, and in general do not examine in detail sectors, end-uses, or fuels that are not explicitly subject to some kind of policy or regulation. Since economic and private activity drive energy demand, which in turn drives energy supplies, it seems logical to work on understanding these driving forces better if public and private authorities are concerned about energy.

Political controversy over California's energy policies has also boosted public and private interest in energy. "How energy-intensive is California?" is an important question in the debate of the role of higher energy prices in California. Since California's economy has been historically less dependent upon energy-intensive manufacturing, and California's weather requires less heating use than other states, higher energy prices by themselves will have a far smaller impact on California's economy than in states with colder winters or more energy-intensive manufacturing.

Similarly, measuring the impact of various efficiency standards and programs has always held interest in Sacramento. The various state measures requiring minimum efficiency in buildings and appliances are subject to various political and legal challenges from time to time. Have these policies saved energy? This report presents evidence that energy intensities of buildings and equipment, including appliances, declined over time coincident with these policies. Further, while California policies may sometimes spill over into national impacts, there is evidence that California energy efficiency in residential and commercial buildings improved faster than U.S. energy efficiency. Have these changes enhanced our economic welfare? Although the data are sufficient to demonstrate increased energy efficiency over time, analysis of economic efficiency is more difficult than energy intensity because: (1) a world without policies is purely speculative; (2) many other factors changed over time, perhaps influencing energy consumption; and (3) data collection and analysis have been insufficient to date to separate other economic factors from the effects of energy policies.

[3] Arguably a recent study of Estonia (population 1.5 million) uncovered more details of the structure of energy use there than efforts had for California (Schipper, Martinot et al. 1994). Even with the uncertainties in dealing with planned economy data, the authors of that study felt that the figures presented a reasonable picture of the entire energy economy.

Equally important, some people have taken aim at utility-sponsored DSM programs, particularly those funded from ratepayers in general. Are they leading to energy savings above and beyond what might be occurring "anyway?" In practice, quantifying the impact solely attributable to a particular DSM program is very difficult. California has led the nation in implementing many DSM programs, and California has encountered difficulties in accurately attributing observed changes strictly to a single cause (the DSM program itself) in the presence of confounding factors such as technological change, other economic signals, and consumer preference factors. The diversity of DSM programs, and the means by which they are implemented, preclude generalization.

The issues of state or utility programs raises yet another controversial issue: How much of the change in energy use in California was "caused" by higher energy prices, how much by these programs? To answer that question correctly would require data covering a stable baseline period over which we could estimate price and income elasticities for specific end-uses later subject to no changes other than energy-efficiency programs or standards, something virtually impossible to do in a dynamic real world situation. We chose to focus on the bottom-up analysis of energy use in California in order to identify the role of each sector and subsector in the evolution of the structure of energy use. The dilemma is that economic analysis at an aggregate level fails to account for the important structural and activity changes over time, yet there is insufficient data at the level of end-use detail to use econometric analyses to estimate price and other impacts separately. Alternatively, we could have attempted to compare the evolution of energy use in California with that in another state without similar programs, which also poses the difficult challenge of holding all else equal. Therefore, in this study, we limit ourselves to examining this question by comparing changes in California with those in the U.S. as a whole, not a wholly satisfactory approach but the only one available given data limitations.

Finally, concerns over carbon dioxide emissions at local, state, national, and international levels require better understanding of trends that may be raising or reducing emissions. At present, California possesses a good inventory of fuel consumption but poor knowledge of how that fuel consumption is related to activities in the economy and in households. This study will not provide an inventory of carbon dioxide emissions, but will provide a unique portrait of energy use in California that could easily be transformed into one showing carbon dioxide emissions by end-use.

In response to these issues, energy suppliers as well as public authorities must sharpen their analysis and forecasting tools. One important element of this improvement would be to build a better historical database and analyze the underlying trends driving energy demand in California. We found the database used by CEC and other authorities insufficient for good analysis (in comparison with those used by the U.S. Department of Energy [DOE] and authorities in many other countries).

## 1.3. Aggregate Comparisons: Why They Don't Work

Figure 1.1 shows the ratios of electricity, final energy use, and primary energy consumption to GSP in California over time. Figure 1.2 compares the ratio of energy use to Gross Domestic Product (GDP) (and energy use per capita) for California and the U.S. for two years. Given all of the difficulties in assembling detailed data for California, why not instead measure differences in efficiency by comparing these aggregates of energy use over time, between regions, or indeed between countries? Unfortunately, this measure would be unsatisfactory and often misleading because it would aggregate sectors and mix components related to the efficiency of energy use with those related to other, equally important characteristics of the energy-use economy.

Schipper, Meyers et al. (1992 and many references therein) presented the fundamental reason why such comparisons show little: the aggregate comparison blends too many structural and intensity differences into the same aggregate indicator, making it impossible to separate out similar energy uses for comparison. For example, Japan has a very low energy per GDP ratio compared with the U.S., usually attributed to greater technological energy efficiency in Japan. Yet the two most prominent components of this difference are the ratio of total house area to GDP (more than a factor of two in favor of the U.S.) and the ratio of car use to GDP, about a factor of three in favor of the U.S. All else equal, these two differences in the structure of energy consumption lower energy use in Japan relative to the U.S. by nearly 20%! And while Japanese homes use far less heat per square meter and per degree day than those in the U.S., they heat to far lower temperatures in a climate with only two-thirds as many degree days as in the U.S. By contrast, Japanese cars use about 80% as much fuel/km as American cars. Thus in comparing heating and driving, the overwhelming components of the large (almost 3 to 1) difference in per capita energy use have very little to do with the "efficiency" with which energy is used. Only in the manufacturing sector is there a clear difference in energy efficiencies (to the favor of the Japanese). Ironically, this difference is blurred because energy-intensive manufacturing is relatively more important in Japan than in the U.S., raising energy use in Japan relative to that in the U.S. The verdict is clear: the aggregate comparison obscures the very elements of energy use we want to examine. In this study we will see that the differences in the ratio of energy use to GDP in California and the U.S. in Figure 1.2 overstate the impact on the U.S./California comparison of lower energy intensities in California, relative to the U.S.

Problems arise in interpreting changes in the ratio of energy use to GDP over time. These are caused both by changes in individual energy intensities and changes in structure. In the case of Japan, for example, changes in the mix of goods and services produced and consumed over the 1973-1991 period (i.e., changes in the structure of energy use) account for almost half of the decline in the ratio of energy/GDP there.

Clearly, since one focus of the present analysis is to highlight the role of changes in energy intensities over time in California, we cannot rely on the ratio of energy to GDP as a measure of changes in energy intensities in California. This means that changes in energy intensities represent only one component of the falling trends in Figure 1.2.

Finally, aggregate comparisons "lose" that part of energy use that is related to climate. While regression techniques that included climate as an independent variable could capture some of this relation, it is more useful to isolate those components of energy use most affected by climate - space heating and cooling.

There are additional problems that arise when making comparisons with states or other entities below the national level. These problems arise because of borders and accounting uncertainties. Aggregate energy use, for example, includes considerable energy use in interstate commerce not necessarily part of California's "energy productivity profile": interstate trucking and rail; interstate and international air travel; transit traffic of all modes. At the same time, the aggregate comparison misses an important import (or export) of raw materials into (or out of) any single state. Finally, there are the problems of people (and vehicles) crossing borders often in small states, people registering their automobiles in states with lower fees or insurance, and people spending significant amounts in states other than where they live. In these regions, it is almost impossible to use aggregate energy.

An alternative normalization for analyzing aggregate energy use is population. According to the U.S. DOE/Energy Information Agency (EIA) *Annual Energy Review* (1993), California ranks second in total primary energy consumption among states, with 8.0 of 82.1 Quads of primary energy consumed in the U.S. However, California ranks 46th in consumption per capita (230 Mbtu/capita compared to U.S. average 322 Mbtu/capita). Indeed, the CEC *Energy Efficiency Report* (1990, 1992) makes extensive use of per capita energy use by sector. The problem with this normalization is that other variables, in addition to population, may be the chief driving variables of a sector. Even in the household sector, population drives demand through the characteristics of housing, appliances, and families. These elements of the structure of household energy use are absent from analysis based only on per capita sectoral demand. Certainly, per capita comparisons of sectoral use make a useful introduction to patterns of energy use. But lacking structural variables, these comparisons cannot yield much information on energy intensities.

## 1.4. Organization of This Report

This report is organized in three basic parts. First, in the introduction we raise broad issues and discuss how we hope to deal with them. We present key definitions and terminology, and show which parts of California's energy use we will analyze. Second, we present analysis of each major end-use sector, discussing data sources and assumptions, presenting indicators of the structure and intensity (or efficiency) of energy use, and making an analysis of changes in these components of energy use over time. We compare each sector with the corresponding sector in the U.S., and analyze the development of energy prices. Then, we integrate our findings for California, focusing on the 1978-1991 period for which data are the most complete, and compare these integrated findings with those for the U.S. Third, we present our overall conclusions. We also present a brief set of recommendations for further data sources and analysis, and include a detailed table of our quantitative findings that summarizes each of the sectoral data files provided separately to the CEC.

## 1.5. Key Terminology

In this study we often depart from usual terminology to describe our data, our procedures, and our results. This section defines important terms as we use them:

### 1.5.1. Energy Intensity, Energy Efficiency, Energy Productivity, and Energy Conservation

There is much confusion over what is meant by these terms. Most observers, however, agree that the first three of these terms refer to the relation between energy consumption and activity, output, or distance, usually considered for a homogeneous activity like production of a commodity, transportation by a given mode, or heating of a home. In part, the *Energy Efficiency Report* issued from time to time by CEC lends somewhat to this confusion, because the report itself has few indicators of "efficiency" that use these kinds of concepts. Nevertheless, this confusion exists well beyond that report.

The confusion arises because "efficiency" has two connotations. In an economic context, "efficiency" connotes whether a given good or service is produced for lowest cost, i.e., maximizing output for all inputs. Energy efficiency also connotes the ratio of output for energy inputs (i.e., ignoring other inputs). This connotation is well founded in mechanics and other aspects of physics applied to any process. But using it within an economic context is difficult, because virtually every economic activity consists of a myriad of physical processes taking place both serially (i.e., heating, drawing, mixing, cooling, drying) as well as in parallel. **In this report, energy efficiency (or energy productivity) means the ratio of output (or activity) to energy use in the physical sense.** Thus a car that uses less fuel/km than another primarily because it is smaller and less powerful is "more efficient" than a larger car. Many drivers perceive greater benefits from driving a larger car rather than a smaller one. However, it is generally true that a large, powerful car of a given vintage and propulsion and emissions control technology is associated with more environmental damage than a small one with the same technology.

To avoid some of this confusion in this report, we refer to a more specific quantity called energy intensity, or energy use per unit of activity. This takes many forms (many of which are listed in Table 1):

- Energy use per unit of physical output in manufacturing (lacking such data, we do not use this in this report);
- Energy use per unit of output (in $) in manufacturing or services;
- Energy use per unit of floor area or GDP in services;
- Energy use per distance travelled, per passenger mile, or per ton mile, in transportation;

and so forth. The inverse of this quantity is energy productivity.

"Energy conservation" is a term often used to describe "saving energy." In this context, "conservation" means both investing in systems to reduce energy intensities or demanding less output, i.e., heating to lower temperatures, driving less, producing less steel.[4]

"Saved energy" is measured by comparing energy use for a given activity before and after a change takes place. In this report, for example, we often compare energy use in 1978 and 1990 holding activities or output constant but letting energy intensities vary. This is one way of computing "saved energy."

The phrase "structure of energy use" refers to the mix of activities for which energy is used. For some sectors, that mix is easily defined: share of output in manufacturing (in $), shares of travel, or freight by mode. For the household sector, the "mix" really refers to the relationship between area heated, area lit, mouths fed, baths taken, appliances owned and used. Measuring these quantities is difficult, and comparing them even harder, since they do not have a common denominator. For the services sector, "mix" is easy to define as area lit (to a given level), volume of air ventilated, computing power, total power of motors, etc--but virtually impossible to track because of enormous data problems. In this report, our "accuracy" in measuring the structure of energy use

[4] Note that this definition is broader than that in use by some observers. President Jimmy Carter's famous "sacrifice" speech (televised to the nation in February, 1977) appealed to Americans to conserve energy in the sense we define it here; later, Vice President Walter Mondale wrote to one of us admitting that emphasizing higher energy productivity would have been more palatable politically!

is highest for manufacturing, relatively high for travel (and for some modes of freight), low but still usable for households, and very low for the service sector and for truck freight, for which we lack measures of output.

In the end, energy intensity (energy/activity) times structure (the mix of activities) gives total energy use. In fact, this is an identity. The reason we want to make the disaggregation is simple: national and international trends in technology, energy prices, and state and national policies affect energy intensities, the measurement of which is the main goal of this report (and the *Energy Efficiency Report*). Trends in demography and lifestyles, international competition, and technology as well affect the structure of energy use, but energy policies and energy prices are somewhat less important to structural changes than they are to intensity changes. Both structure and intensity affect total energy use, and we want to measure both components. Hence the disaggregation and the need to define approximately 25-30 activities (or outputs) in the economy for which energy is used.

### 1.5.2. Energy Consumption

Energy consumption means conversion of primary fuels and electricity to work, light, and information, and ultimately to heat. Unfortunately, there is no unambiguous way of measuring energy consumption or energy use. We use several definitions.

- Delivered (final, site) energy counts consumption at the point of final use only.
- Primary (resource) energy use counts delivered energy and losses in the production of electricity and, ideally, other fuels counted in delivered energy.

In practice, the energy required for making electricity available to final users so dominates the difference between delivered and primary energy that we focus on this extra quantity.

- Useful energy is a form constructed when we need to aggregate fuels subject to combustion losses with electricity (with no local losses in combustion), namely for space and water heating and cooking.

Useful energy is important for comparing energy intensities of space heating, water heating, and cooking in California with those in the U.S. as a whole because the share of households using electricity for these end-uses is higher in the U.S, and in both regions this share has changed over time. Were we to use delivered energy, the lack of on-site combustion losses in using electricity means that increasing electricity use gives the appearance of energy saving, when in fact energy substitution has occurred. Were we to count electricity at its primary value, then we likely would show an increase in energy consumption because of the losses incurred in producing electricity. The concept of useful energy provides a "useful" compromise by removing an average of 33% of the energy in oil and gas to reflect average losses in combustion.

### 1.5.3. Climate

California's climate has far fewer heating degree-days (HDD) and slightly more cooling degree-days (CDD) than the U.S.[5] Using the 21-year (1970 to 1990) average, California population-weighted annual HDD are 1784, only 36% of the U.S. HDD (4876). California population-weighted annual CDD (1334) are about 117% of the U.S. CDD (1137).

Climate is an important structural variable in our analysis. Variations in average winter and summer temperatures may have a nearly linear impact on energy use for heating and cooling respectively. Moreover, differences in the long-term outdoor temperatures between regions give rise to significant differences in demands for these end-uses between regions. For the residential and commercial sectors, energy data for each of 16 climate zones was normalized for the weather in that zone, prior to aggregation over zones to obtain state totals. For comparisons with the U.S. we used HDD and CDD weighted by U.S. population as derived by LBL from the U.S. Meteorological Survey and data provided in DOE's Residential Energy Consumption Survey.

### 1.5.4. Sectors Considered

To illustrate the sectors covered in the study, consider Figures 1.3 and 1.4. Figure 1.3, from *California Energy Statistics,* shows California's primary energy use by fuel. Figure 1.4 shows the disposition of primary energy, i.e., showing final energy use (analyzed in forthcoming sections), losses in production and distribution of electric power, and energy consumption that we cannot allocate to any final energy use. This last is comprised mostly of oil, which in turn is predominantly oil used for refining and industrial uses outside of manufacturing, shipping (including bunkers), and air travel (most of which is out of the state).

In this report we have divided California's energy use into several key sectors. They differ somewhat from those most often considered. California's official balances show

[5] Heating degree days are the annual sum over the difference between 65°F and lower hourly temperatures, for a weather station representing a climate zone. Cooling degree days are the annual sum over the difference between higher hourly temperatures and 65°F.

State-level values are calculated as weighted averages over 16 climate zones defined by the CEC. The weights are households (for residential) and total floorspace (for commercial). U.S. values are population-weighted.

Utilities, Industry, Residential, Commercial, and Transportation. Several of these, however, are too large or inhomogeneous for the present analysis. Hence we make the following breakdowns:

- The Residential (household) sector, following CEC definitions and data;
- The Commercial (service) sector, following CEC definitions that limit considerations to energy uses in buildings and omit utilities and street lighting;
- The Manufacturing Sector, defined as those industries in Standard Industrial Classifications 2 and 3;
- The Travel sector, including activities with cars, personal light trucks, and passenger transportation for hire by various modes;
- The Freight sector, including remaining use of trucks, inland shipping, rail, pipelines, and other modes of freight;
- Other Industry (a residual sector not considered in detail because of data problems), including agriculture, mining, construction, and, unfortunately, many miscellaneous uses that would be considered part of the energy conversion sector, such as coal benefaction, field losses from natural gas production, refining losses, water pumping, street lighting, and municipal utilities in some nomenclature.

Energy use in the sectors we analyze is shown in Figure 1.5. Note that final energy use is included in this figure for comparison, as well as the losses incurred in both producing and distributing electricity. In Figure 1.6 we show the energy-use sectors with these electric power system losses distributed in proportion to the sectors in which electricity is consumed. In this study we have not considered the main energy conversion sectors of electric utilities and refining explicitly. When we refer to the "primary energy use" for a given purpose, we include these losses related to electricity production.

## 1.6. General Data Considerations

The data shown in Figures 1.5 and 1.6 suggest that about 10% of California's final energy use cannot be directly allocated to activity taking place in California, shipping, and air travel. Additionally, however, there are few data showing how much freight is hauled in California, and no accurate data (other than GSP) that present output for the Other Industry category. Finally, the data for manufacturing are somewhat uncertain because they count only purchased energy (up to 1981). This means crude oil losses in refining and the wood wastes used in the lumber and paper industries are excluded.

After 1981, the data for manufacturing oil and solid fuels (mostly coal) come from a different source than those for manufacturing gas and electricity, but the waste biomass appears to be excluded. Since oil and solid fuels only account for a small amount of the total energy in manufacturing, this undercount is small, as is the exclusion of biomass. Overall, however, we face significant uncertainties that represent together nearly 20% of the final energy consumed in California.

It is therefore not surprising if measuring the "efficiency" of California's energy use is difficult. The two *Energy Efficiency Reports* we reviewed lacked many of the most important structural data that describe California's economy. Important omissions included a lack of disaggregated measures of manufacturing activity and energy use and a near absence of disaggregated measures of vehicle use, travel (passenger miles by mode), or freight (ton miles by mode) in the transportation sector. In this study we found that data required for most of these measures could be assembled.

In this report we prefer to rely on California data. Ironically, however, many California data are available only from federal authorities. Thus we turned to the U.S. Census of Manufactures (to 1981), for data on energy use in Manufacturing. For GSP, we relied on data from the California Department of Finance that in turn come from the U.S. Department of Commerce.

Residential and service sector data for California were taken exclusively from California sources. For transportation, we relied principally on Caltrans, CARB, and Department of Motor Vehicles for data on vehicle ownership, use, and fuel use. Although the federal government publishes many of these data, we know they come principally from state authorities, so we chose to use these authorities. However, we turned to federal authorities for data on transit, rail, and air activity, as these have not been collected by state authorities since the late 1970s.

We encountered several generic problems in our work. The CEC has kept its own energy balances for California, covering the period 1976-1991 (1992 were not yet available). These in turn are derived from the DOE State Energy Data System (SEDS). Wood use, which is estimated by some DOE documents at the national and state level for some years, was not included in California's data. Moreover, California's version lacks some fuels (noted in the various sectoral sections below) and lack a transparent accounting of the electric power sector. That is, we could not find a single, unambiguous accounting of how much fuel was used for each kind of power production and how much power was produced by that power source.

Our U.S. data come from a series of previous studies (Schipper, Howarth, and Geller 1990). These have been updated to 1991 using recent DOE surveys. Because 1991 was a recession, we use 1990 as the final year of comparison between the U.S. and California.

## 1.7. Indicators of Structure and Intensity using LBL Models

Table 1 lists the major indicators we aimed to produce for this study. Data limitations preclude us from measuring many of them, such as those associated with freight transportation. In other cases (i.e., passenger transportation), we have been able to measure activity and energy intensity for part, but not all, of a sector. For some indicators, data permit us to follow their evolution over time. This in turn permits us to compare measures of energy intensity (or even the structure of energy use) across sectors to see which changed the most in a relative sense over time. Finally, many of the indicators we developed may be compared with similar ones we have derived for the U.S. as a whole. This comparison does not say "who is better," but does show "who is different."

| Table 1: Sector/indicator | Indicators of Energy Use, Structure, and Intensity Definition/description of factors |
|---|---|
| RESIDENTIAL | |
| Activity | Population |
| Intensity | Space heat energy per unit of home floor area, electricity per appliance, energy per capita for cooking and hot water adjusted for home occupancy, lighting energy use per unit of floor area |
| Structure | Household floor area per capita, persons per household, appliance ownership per capita |
| MANUFACTURING | |
| Activity | Manufacturing value added |
| Intensity | Industry group energy use/value added |
| Structure | Industry group value added shares |
| OTHER INDUSTRY | |
| Activity | Value added in agriculture, forestry, fishing, mining, and construction |
| Intensity | Energy use/value added |
| Structure | Not applicable (activity not disaggregated) |
| SERVICES | |
| Activity | Service sector value added |
| Intensity | Energy use/value added |
| Structure | Share of Value Added in Sub-Sectors |
| PASSENGER TRANSPORT | |
| Activity | Passenger-km/year |
| Intensity | Modal energy use/passenger-km |
| Structure | Modal mix |
| FREIGHT TRANSPORT | |
| Activity | Tonne-km/year |
| Intensity | Modal energy use/tonne-km |
| Structure | Modal mix |

Figure 1.1

# California Energy Aggregates

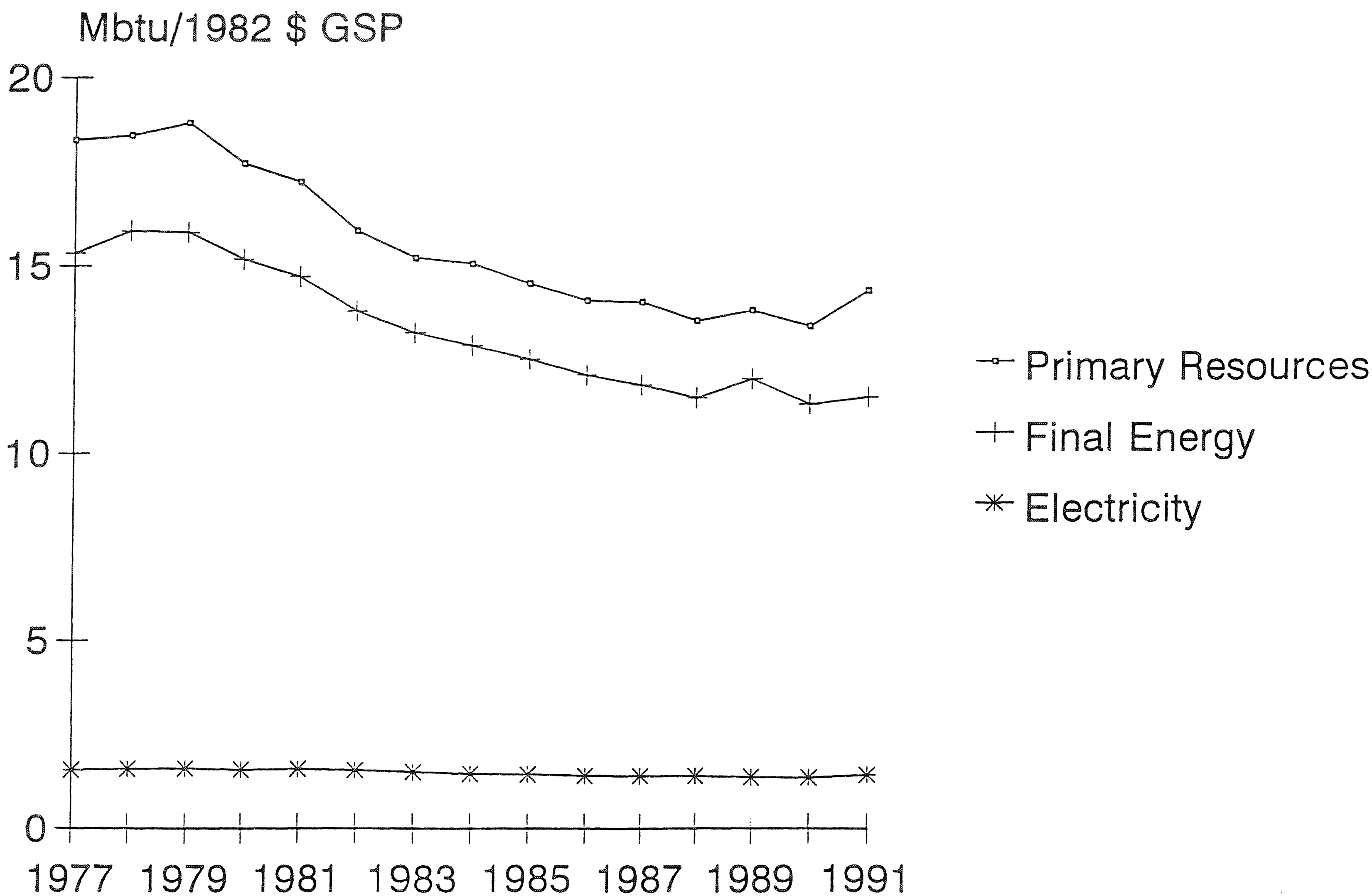


Figure 1.2

# Aggregate Energy Use: Calif/USA Ratios

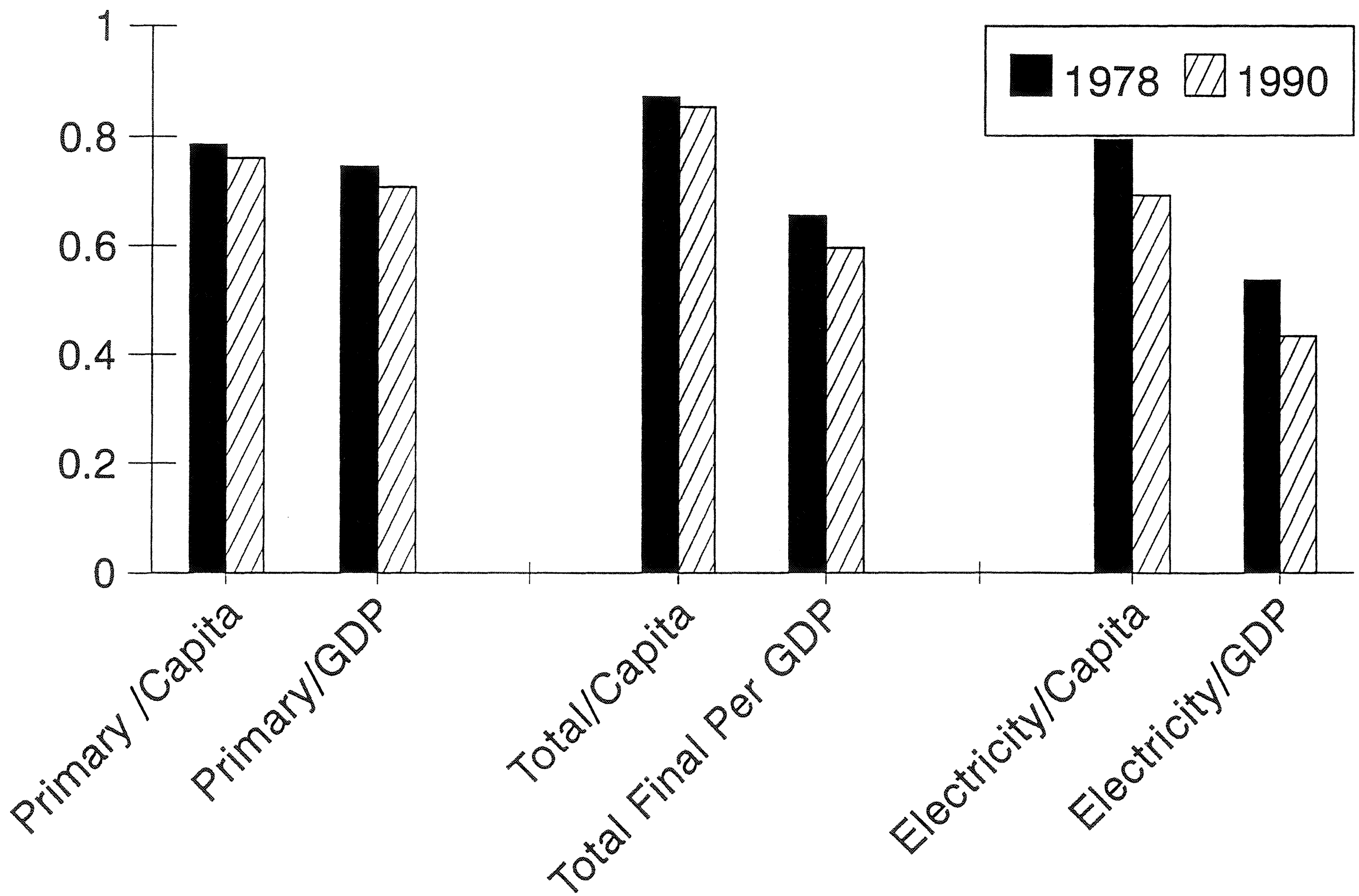


Figure 1.3

# Primary Energy Use in California

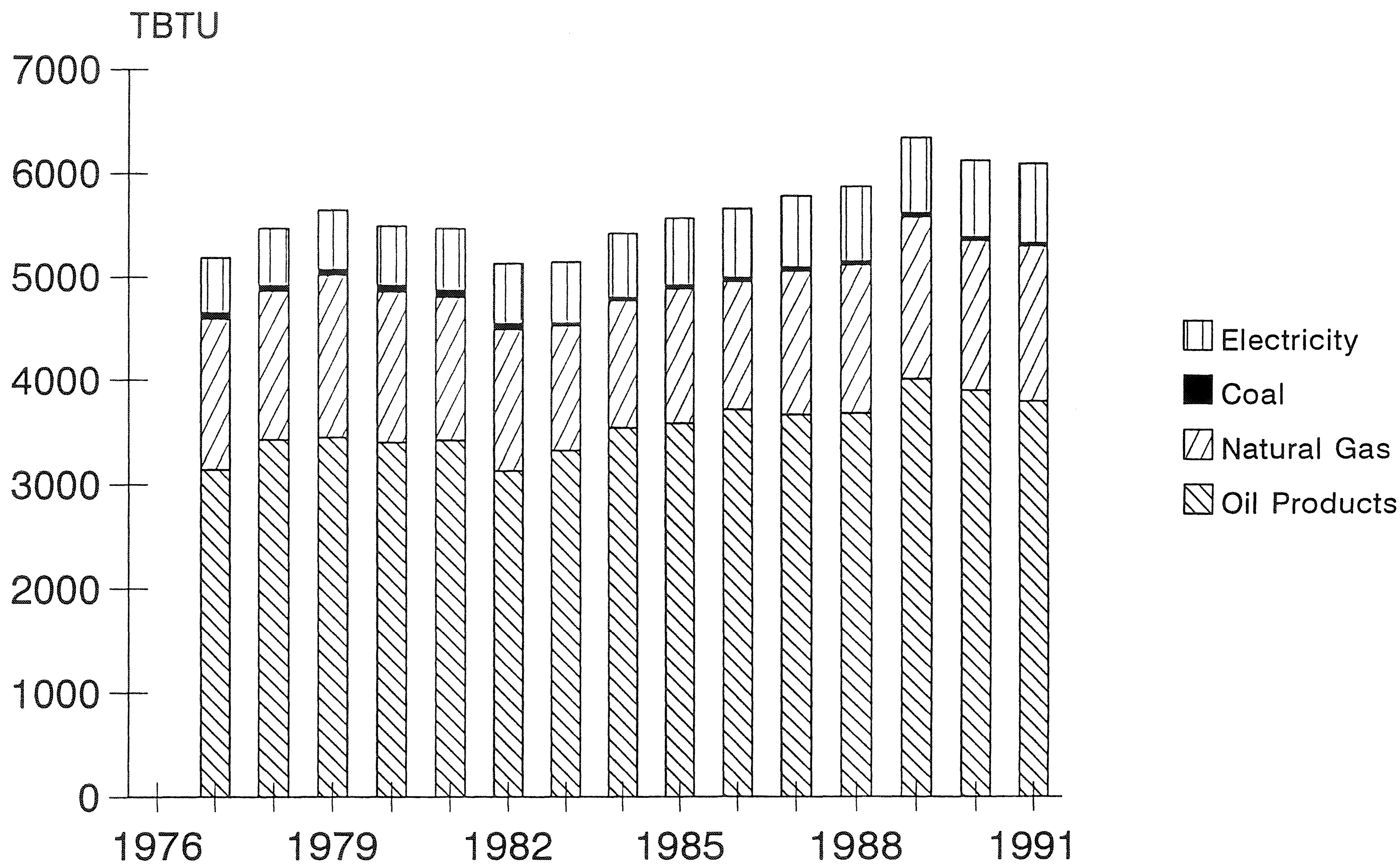


Figure 1.4

# Disposition of Primary Energy Use in California

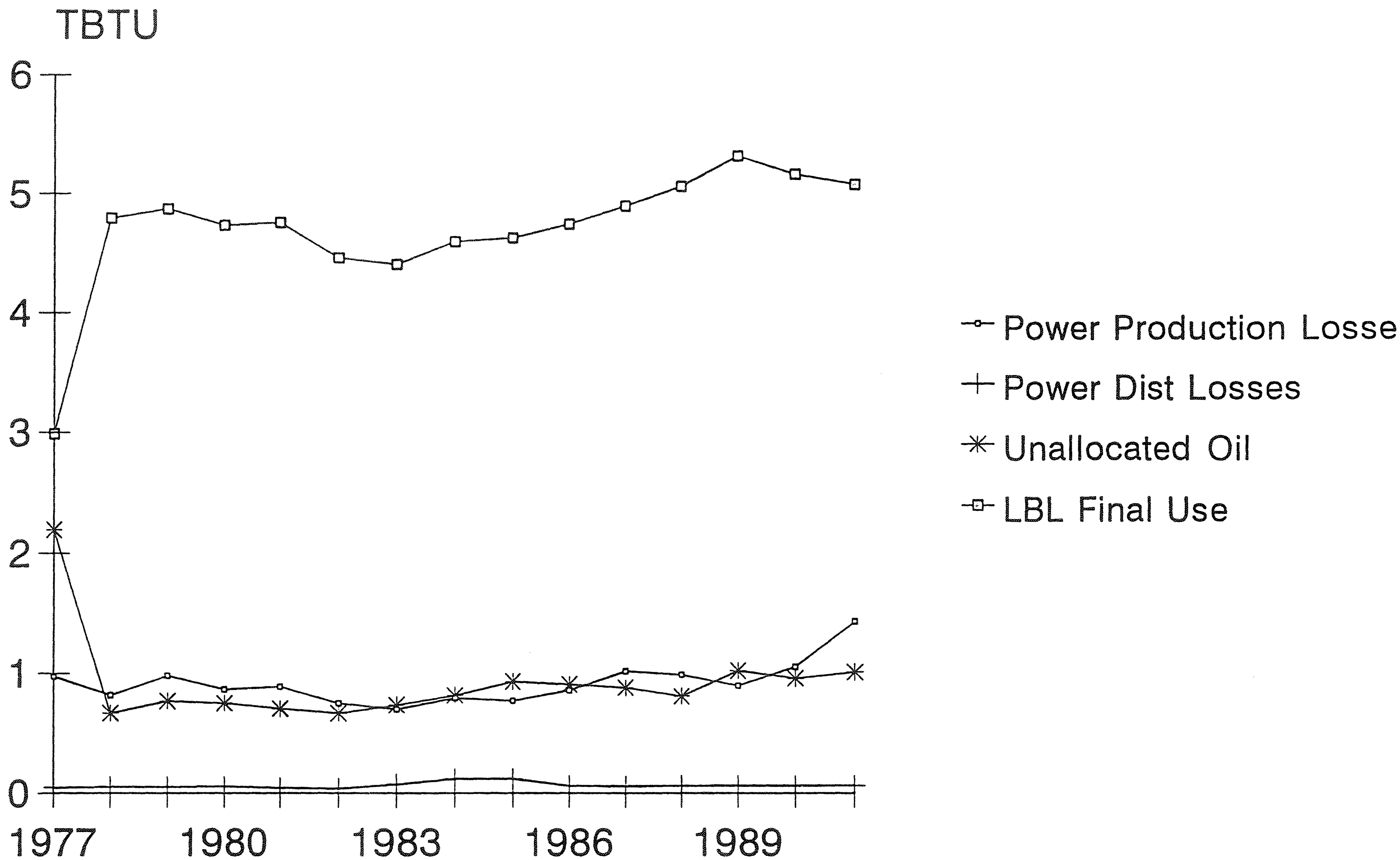


Figure 1.5

# Final Energy Use by End-Use Sector in California

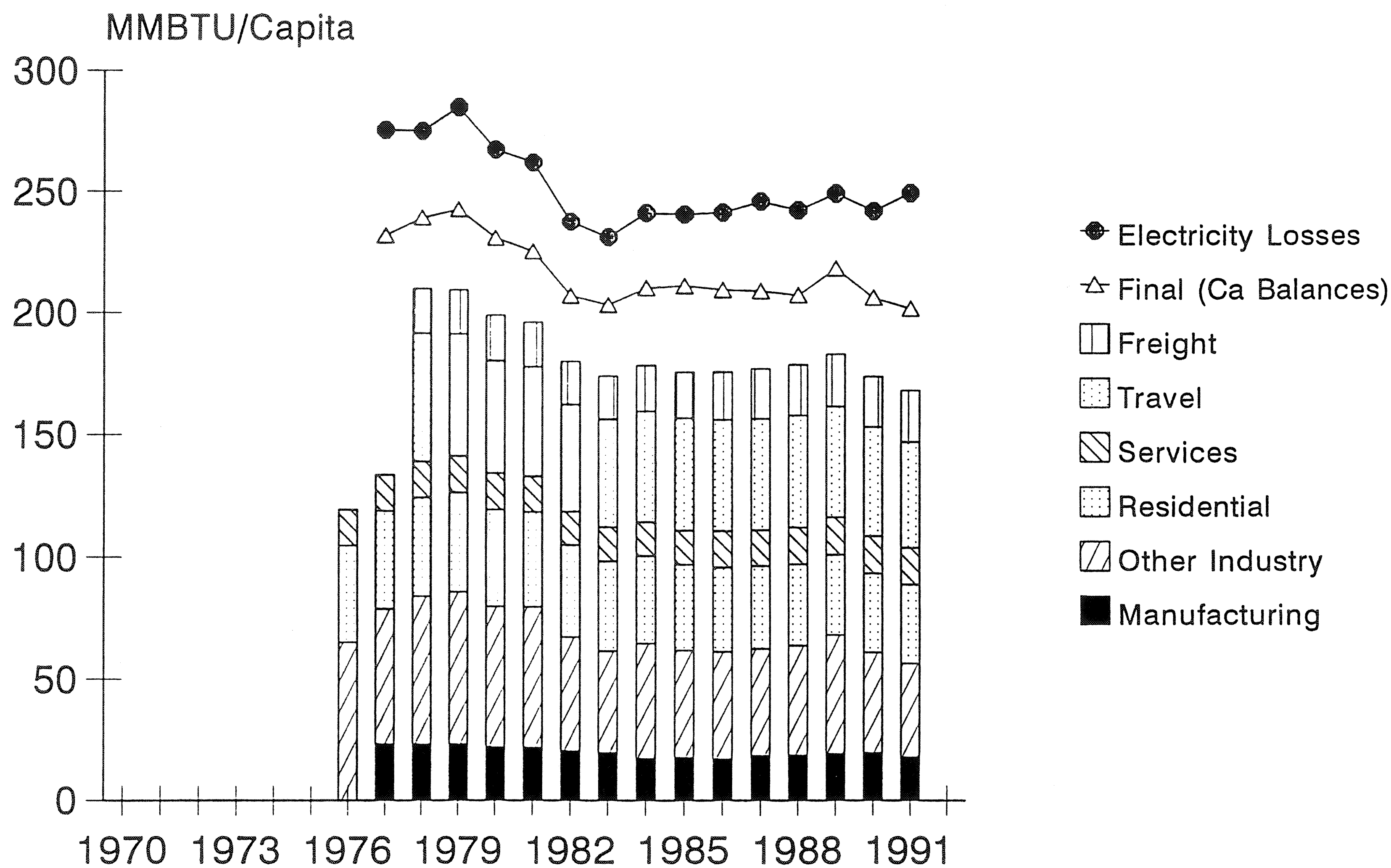
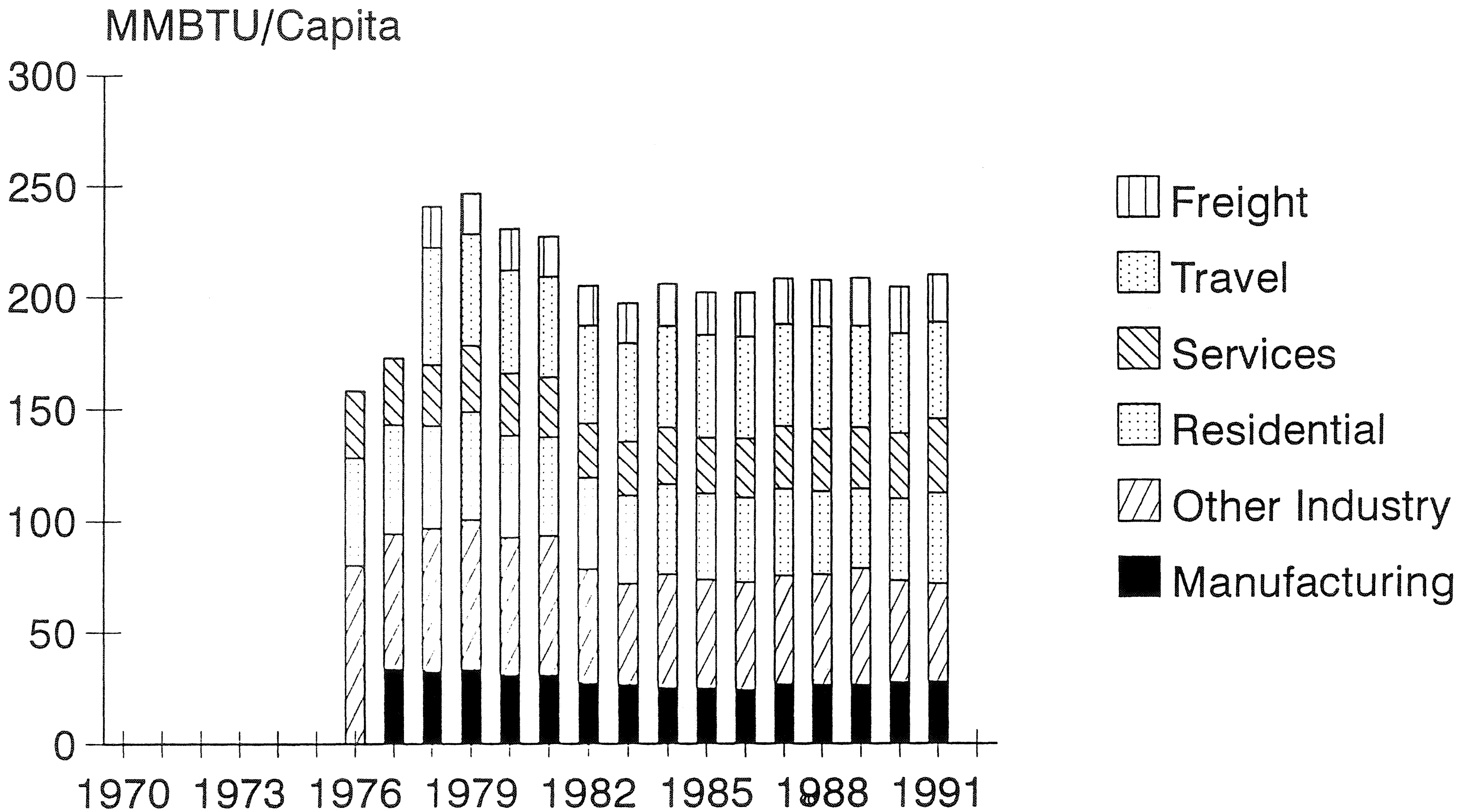


Figure 1.6

# Primary Energy Use by End-Use Sector in California




Electricity Production Losses allocated to sector of use

## 2. RESIDENTIAL SECTOR

The goal in this section is to quantify energy uses, and to measure changes in energy intensities, including those possibly affected by imposition of thermal performance regulations for new construction and appliance efficiency standards starting in 1977.

### 2.1. Data Sources

Data was obtained from the California Energy Commission staff[6] and represents the database associated with the sectoral energy models. Detailed information was obtained for each utility service territory by climate zone (16 zones). This data was aggregated to the state level.

The data appear to characterize sales of electricity and natural gas well. Oil and LPG consumption are included in the energy totals beginning in 1977, but not analyzed in detail. Wood was not analyzed here.

The characteristics of the housing stock in California, as elsewhere in the U.S., are ascertained from periodic surveys, with interpolation between, leading to some uncertainty. Appliance ownership is determined by utility surveys, and is expected to be reliable over time. Information on the efficiency of equipment in stock is always sparse, least certain in the earlier years, and more certain over time due to labeling, standards, and DSM programs. Explicit time-series statistics on sales of equipment by efficiency characteristics is lacking for most products at both the state and national level. Uncertainties in the most detailed indicators, average unit energy consumption by end-use, arise from their derivations by various methods, since direct measurements represent only a small subsample, and there is large variation in field usage among the diverse population.

Data on residential energy consumption was obtained from DOE reports, including Residential Energy Consumption Survey and technical support documents for various federal appliance efficiency standards, and from LBL reports.

### 2.2. Definition

Residential energy is defined as all energy consumed in single family, multi-family, and mobile homes. This includes electricity or natural gas used for space heating, water heating, air conditioning, cooking, clothes drying, miscellaneous uses of gas (pools, hot tubs, etc), major electric appliances, lighting, and small appliances.

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[6] R. Rohrer, personal communication, 1994.

## 2.3. Aggregate Trends

California residences consume less energy on average than U.S. residences. California residences are in a significantly milder heating climate. California residences contain more people, and less floor area, on average, than U.S. residences, partly as a result of the difference in mix of housing types.

Figure 2.1(a) shows California's share of U.S. population and Figure 2.1(b) of residential natural gas and residential electricity. California's share of U.S. residential natural gas has increased from 1978 to 1990, but not as rapidly as population. Its share of U.S. residential electricity has remained well below California's share of U.S. population. California's share of U.S. residential electricity increased from 1978 to 1984, and then declined significantly through 1990.

### 2.3.1. Population and Household Size

The California population is growing more rapidly than the U.S. population. Figure 2.1(a) shows the California population as a fraction of U.S. growing from 9.6% in 1970 to 11.6% in 1990.

In addition, California has more persons per household. The number of persons per U.S. household consistently declined from 3.16 in 1970 to 2.62 in 1990. Figure 2.2 shows that persons per California household declined from 2.99 in 1970 to 2.75 in 1980, but increased from 1982 to 1985 and again in 1989, reaching 2.86 persons per California household in 1990 (near the 1975 California level, or the 1979 U.S. level). In 1990, the average California dwelling unit housed 2.86 persons, a difference of 0.24 (9%) more than the 2.62 persons per U.S. dwelling.

### 2.3.2. Energy per Dwelling Over Time

Residential final energy declined 27% from 110.9 GJ/dwelling in 1970 to 81.2 GJ/dwelling in 1993. Most of the decline occurred in the period 1978 to 1985 (14.8 of 29.7 GJ/dwelling), compared to declines of 8.9 GJ/dwelling (1970 to 1978) and 6 GJ/dwelling (1985 to 1993). (Since oil and LPG are not included in the totals prior to 1977, comparisons to the earlier years are approximate.)

### 2.3.3. Decline in Per Capita Residential Energy

Residential final energy per capita declined 23% from 37.0 GJ/capita (1970) to 28.6 GJ/capita (1993). The greatest change occurred in the period 1978 to 1985, a reduction of 5.8 GJ/capita, compared to declines of 0.5 GJ/capita from 1970 to 1978 and 2.1 GJ/capita from 1978 to 1993. (Again, since oil and LPG are not included in the totals prior to 1977, comparisons to the earlier years are approximate.)

## 2.4. Structural Trends

The largest structural difference is climate, as discussed above. California has only 36% of U.S. HDD, but 177% of U.S. CDD. Other structural differences include: California has a higher share of multifamily housing (and lower share of single family), and, in recent years, less floor area and more persons per dwelling than the U.S.

California homes rely overwhelmingly on natural gas, with very few homes heated with oil or LPG and a small share (<5%) using electricity.

### 2.4.1. Housing Type and Floor Area

The mix of housing types shows a lower fraction of single family units (61% California vs 69% U.S.), and a higher fraction of multifamily units (34% California vs 26% U.S.) in 1990.

The average floor area per California dwelling was higher than the average U.S. dwelling from 1970 to 1977, but average dwelling size grew faster in the U.S. By 1990, the average California dwelling was 1442 sq. ft., 8% less than the average 1569 sq. ft. for the U.S. dwelling.

## 2.5. Fuel Mix

The mix of fuels used in California households is atypical for the U.S., being composed almost totally of natural gas and electricity. Small quantities of heating oil and LPG are used in areas far from the gas grid, and an unknown amount of wood is used for space heating.[7]

### 2.5.1. Gas Appliance Shares

The most important structural difference between California households and the U.S., shown in Figure 2.3, is that California households have a higher share of gas compared to U.S. households for all major gas-consuming end-uses (space heat, water heat, air conditioning, clothes dryers, and cooking). These differences in saturations account for the higher than expected share of California compared to U.S. residential gas consumption, and tend to partly offset the lower unit energy consumptions for gas end-uses in California, which reflect the milder heating season. The net result in 1990 is that Californians have lower natural gas consumption per household than the U.S. average

[7] According to the DOE, about 600 PJ (0.58 quads) of wood were used in the household sector in 1991. This compares with about 8000 PJ (7.8 quads) of fuels and nearly 3 (2.8) of electricity. Since the climate in California is milder than in the U.S. as an average and California's population is concentrated away from heavily forested areas, it is reasonable to assume that the importance of wood in California is less than in the U.S. as a whole.

(558 vs 842 therms/year), and lower electricity consumption per household (6607 vs 9447 kWh/year).

### 2.5.2. Electric Appliance Shares

Figure 2.4 shows that California households have lower saturations of electric refrigerators, air conditioning, furnace fans, ranges/ovens, clothes dryers, space heating, water heating, freezers, and waterbed heaters, compared to the U.S. The lower saturations help account for the lower household consumption of electricity. For a few end-uses, California households have higher saturations than the U.S., namely, hot tub or spa heaters, pool pumps, dishwashers, and clotheswashers.

## 2.6. Energy Intensity Trends

In addition to facing increasing energy prices, since the 1970s, Californians have had appliance standards to restrict sales of energy-using equipment to more efficient designs, and building codes to decrease the energy intensity for space heating and cooling in households. Utility programs have included information, rebates, and low interest loans to consumers. A decline in energy intensities over time is apparent.

### 2.6.1. Unit Energy Consumption by End-Use

Unit energy consumptions (UEC) by utility by region from CEC sectoral models are averaged over California and compared to U.S. UECs from a national survey (U.S. DOE/EIA 1992).

The average unit electricity consumption is higher in California than the U.S. for five end-uses: water heating, space heating, swimming pool pumps, waterbed heating, and clothes dryers. For eight end-uses, the average UEC in California is lower than the U.S. average: refrigerators, freezers, cooking, spa heater, furnace fan (consistent with climate), television, dishwasher, and clotheswasher.

For residential gas appliances, average California unit energy consumption is lower than the U.S. average for space heat, cooking, and clothes dryers, but California is higher than the U.S. for gas air conditioning and water heating. The most important difference in gas UECs is the lower UEC for California gas space heating, explained at least in part by the difference in climate.

### 2.6.2. Space Heating Intensity

To make a better comparison of space conditioning intensities, corrections are made for dwelling size and climate, and for the efficiency of the energy delivery system. First, space conditioning energy is corrected for annual variation in climate by dividing by an index (ratio of the particular year's HDD to average HDD for each region). Then, to reduce the effect of changes in fuel choice, space conditioning energy for each fuel is converted to useful energy[8] (eliminating generation and distribution losses, and approximating energy efficiencies) and summed across fuels. Space conditioning energy intensity is then expressed as the ratio of useful, climate-normalized space heating energy to a measure of activity, such as floor area, population, or number of dwellings. Since oil and LPG are not included in the totals prior to 1977, comparisons to the earlier years are approximate.

Figure 2.5 shows that space heating energy intensity per floor area for California has remained lower than the U.S., with the difference largely explained by the milder California climate. The noise in the trend is largely due to the variation in annual HDD. Figure 2.6 shows space heating energy intensity per capita and per dwelling. U.S. space heating intensity per dwelling is larger than California's, primarily reflecting the milder climate in California, and partly because more U.S. dwellings are single family and have larger floor area. In addition to a milder climate, California has more persons per household, so the space heating per person is lower in California.

One method to correct for climate is to divide space heating energy by HDDs. For California, this "correction" substantially increases the year-to-year variation in intensity, rather than decreasing the variation. Nonetheless, the result is interesting, namely that, after accounting for the difference in HDDS, California and the U.S. are similar. Figure 2.7(a) shows space heating intensity per capita per HDD for California and the U.S. California's intensity declines less than the U.S. until the 1980's, and catches up in the 1990s. A hypothetical explanation for the trend is that U.S. households in 1970 had a greater opportunity for improved efficiency than California households. Figure 2.7(b) shows similar results for space heating intensity per dwelling per HDD. Figure 2.7(c) shows space heating intensity per floor area per HDD, in which the recent trend toward lower floor area per dwelling in California, compared to the U.S., amplifies the difference in intensity.

The CEC should undertake additional detailed comparisons between California and U.S. building and equipment characteristics from 1970 to the present to better explain the observed trends.

### 2.6.3. Water Heating Intensity

To permit comparison in spite of differences in fuel choice, water heating energy for each fuel is converted to useful energy (eliminating generation and distribution losses,

8 The calculation of useful energy is approximate, assuming a constant 66% of gas delivered for space heating is useful energy. This calculation could be improved by creating a time series, better reflecting the efficiency improvements in gas space heating equipment and building shells over time, both for California and the U.S.

and approximating energy efficiencies) and summed across fuels. Since oil and LPG are not included in the totals prior to 1977, comparisons to the earlier years are approximate. Figure 2.8 shows residential water heating useful energy intensity per capita and per dwelling for all fuels combined. California has higher water heating energy intensity per capita. In addition, the difference in demographic trends, with increasing persons per household in California, causes the water heating energy intensity per dwelling to be higher than for the U.S.

### 2.6.4. Cooking Intensity

To permit comparison in spite of differences in fuel choice, cooking energy for each fuel is converted to useful energy (eliminating generation and distribution losses, and approximating energy efficiencies) and summed across fuels. Figure 2.9 demonstrates that residential cooking useful energy intensity per capita and per dwelling is similar between California and the U.S.

### 2.6.5. Lighting Energy Intensity

Figure 2.10 shows that California's residential lighting energy intensity is higher per capita than the U.S. The difference is a surprise, and much greater than can be explained by California's additional persons per dwelling. More analysis is needed regarding possible explanatory factors, such as number of fixtures per household, hours of use, and capacity of indoor and outdoor lighting.

### 2.6.6. Appliance Energy Intensity

Figure 2.11 shows a dramatic difference in trend, with U.S. appliance energy intensity increasing, both per capita and per dwelling, while California shows declines from about 1981. California appliance energy intensity per capita is lower than the U.S. beginning in 1977, coincident with the implementation of appliance standards, and before the trend began (ca. 1984) toward more persons per California household.

## 2.7. Detailed Analysis

The factors that contribute to lower residential energy consumption in California, compared to the U.S., include: milder heating climate (36% of U.S.), more gas (and less electricity) appliance shares, and smaller dwelling floor area (greater share of multifamily dwellings). In addition, appliance energy intensity has declined over time in California, in contrast to significant growth in the U.S., coincident in time with California's policies and programs to increase energy efficiency.

Californians in 1990 have lower unit energy consumption for eight electric end-uses: refrigerators, freezers, cooking, spa heater, furnace fan, television, dishwasher, and clotheswasher. Gas unit energy consumption is lower in California than the U.S. for space heat, cooking, and clothes dryers.

Californians are not always less energy intensive. Climate-corrected useful space heating energy intensity appears similar to slightly higher in California compared to the U.S. per capita water heating and lighting intensities are higher in California. The extent to which these may be income effects, or differences in usage behavior, has not been analyzed.

California has higher persons per household and 17% higher CDDs. Average 1990 unit energy consumption is higher in California than the U.S. for five electric end-uses: water heating, space heating, swimming pool pumps, waterbed heating, and clothes dryers. For gas end-uses, California has higher unit energy consumption than the U.S. for gas air conditioning and water heating.

The impacts of appliance standards, building standards, and utility programs may not be easily seen in aggregate energy intensity indicators due to limitations in the data, time lags, and confounding factors. Some specific evidence of the impacts of California's policies and programs is presented next.

### 2.7.1. Appliance Standards

California implemented appliance energy performance standards beginning in 1977, and continuing thereafter. Federal appliance energy performance standards superseded many of the California standards with the passage of the National Appliance Energy Conservation Act of 1987, setting national standards effective in 1990 or later, and subsequent amendments. This section discusses some examples of the impacts of California appliance standards. (CEC 1987)

Gas furnaces. In 1977, California required a minimum 71% seasonal efficiency for gas furnaces, effective December 22, 1983. In 1981, according to industry statistics, over 90% of gas furnaces sold in California had seasonal efficiency between 66 and 70%. In 1984, these had shifted to seasonal efficiencies >/= 71%. Nationally, 76% of sales remained below 71% seasonal efficiency in 1984.

Refrigerators. The result of California standards in 1979 and 1987, and large-scale utility incentive programs beginning in late 1983, changed the distribution of efficiencies sold in California, eliminating the least efficient models from the California market and providing incentives for the production of new, more efficient designs. An example of the impact of utility rebates is presented below in Section 2.7.3.

Room air conditioners. California set minimum efficiency standards in 1979, boosting the average efficiency relative to the national average. In 1983, the national average efficiency (7.29 EER) for new units was still 11% lower than the California average (8.61 EER).

Central air conditioners. The 1979 energy efficiency standard, and later utility programs, boosted the average efficiency of California units above the national average. By 1984, the national average was converging on the California average, probably due to increased utility incentive programs elsewhere (Dickey 1984).

All these comparisons are underestimates of the impact of California standards, since the national averages include California sales. In addition, energy-efficient appliance designs marketed initially in California were subsequently made available elsewhere in the U.S. Ultimately, national efficiency standards were enacted at levels similar to the earlier California standards.

### 2.7.2. Building standards

California has been a leader among states in promulgating energy-related building codes. A recent CEC staff report indicates that California's energy efficiency standards for low-rise residential buildings (Title 24) already exceed the CABO Model Energy Code, as required by the national Energy Policy Act of 1992.

California enacted building standards affecting new construction from 1978 on. One example of the effect is given by a Pacific Gas and Electric company (PG&E) on-site survey in 1986 that showed large increases in wall and ceiling insulation, and decreases in glass U-value for residential buildings constructed in or after 1975, compared to prior construction. These changes are responsible for significant reductions in heating and cooling energy requirements (CEC 1994).

The CEC should compare California and U.S. building characteristics over time, perhaps drawing on data available from the National Association of Home Builders.

### 2.7.3. Utility DSM programs

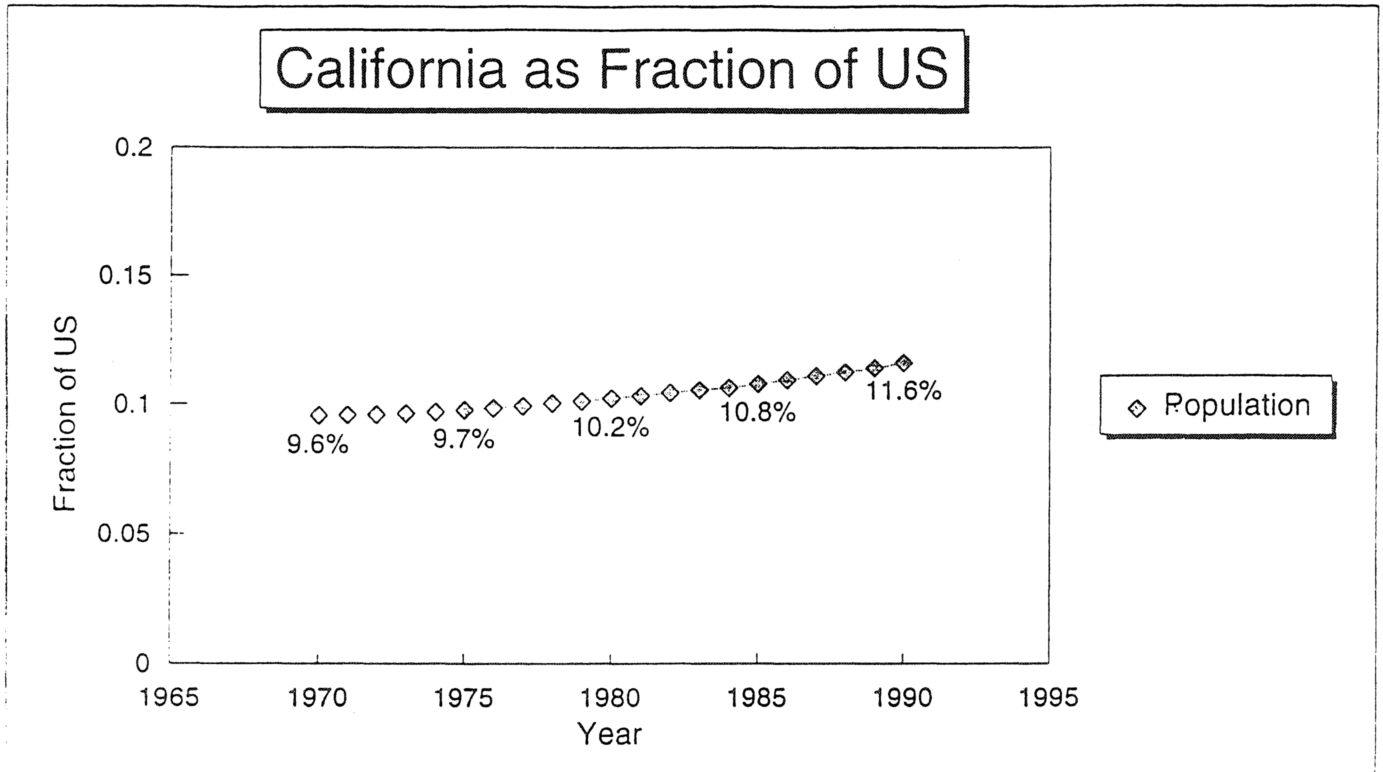
No attempt is made here to summarize California utility DSM programs. Previous reviews of EIA survey data show that California utilities lead the nation in percent reduction in kWh and kW peaks (Hadley 1995).

One example is given here of energy savings from a utility incentive program. The example illustrates important issues in evaluating utility DSM programs, including the need for: a) control groups, and b) market data.

According to a PG&E study (Pacific Gas & Electricity 1992), in 1991, new refrigerators sold in the PG&E service area are more efficient than those sold in the U.S.

Furthermore, no rebound in size or features is observed. PG&E provided rebates to consumers who purchased refrigerators more efficient than the 1990 national standards. The rebates increased with increasing efficiency and were offered from June through September. As a result, during the program in 1991, 54% of summer sales had efficiencies at or greater than 20% more efficient than the national standard, compared to 5% or less of sales in control regions. For California as a whole, including other utility programs, 31% of summer sales had efficiencies at or greater than 20% more efficient than the national standard. Savings in 1991 for PG&E alone are 13 million kWh.

## Figure 2.1(a)




## Figure 2.1(b)

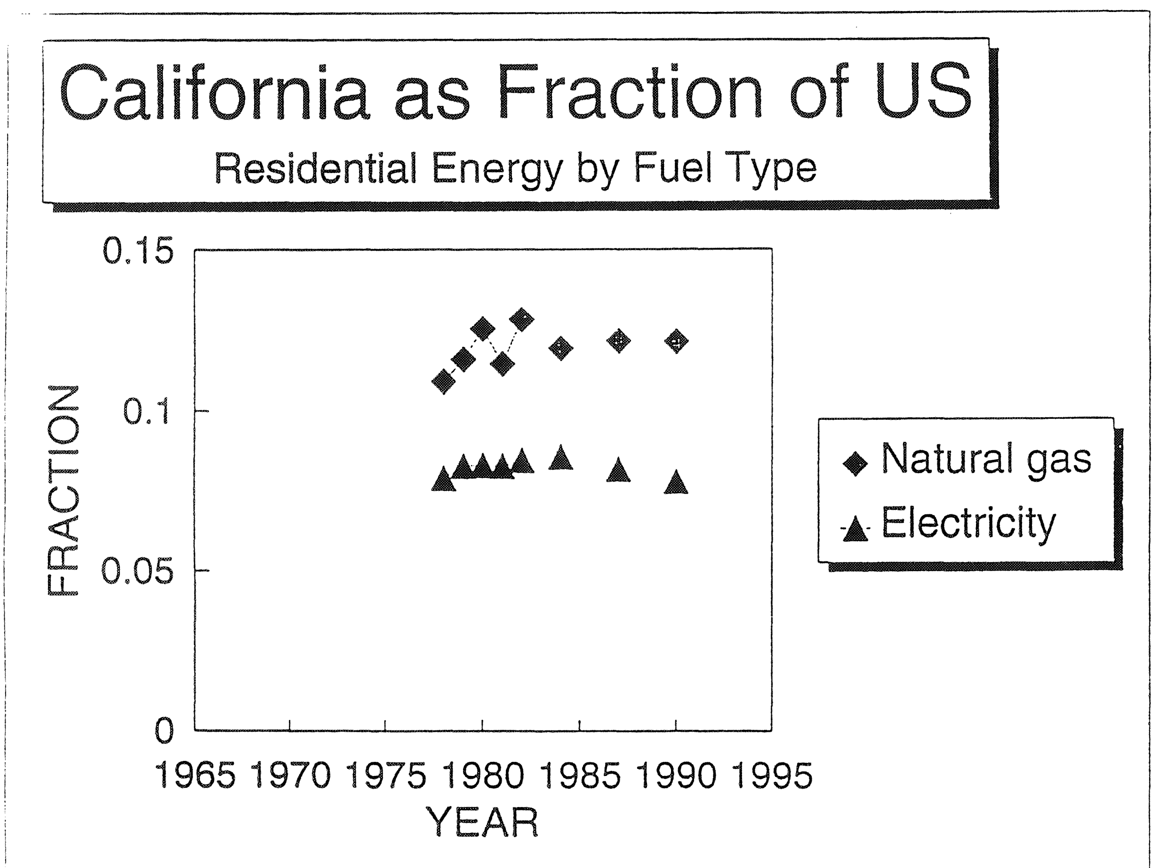


Figure 2.2

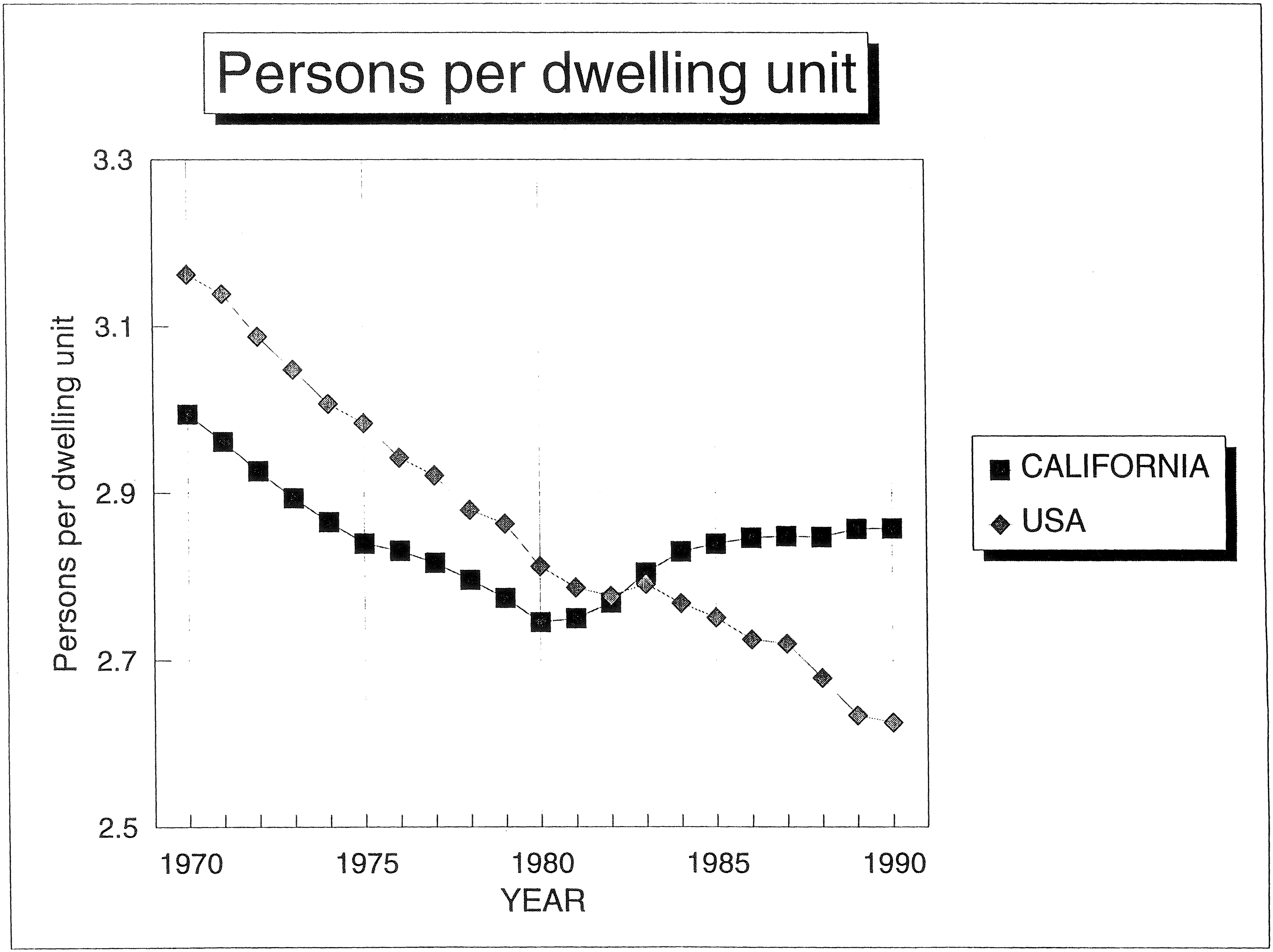
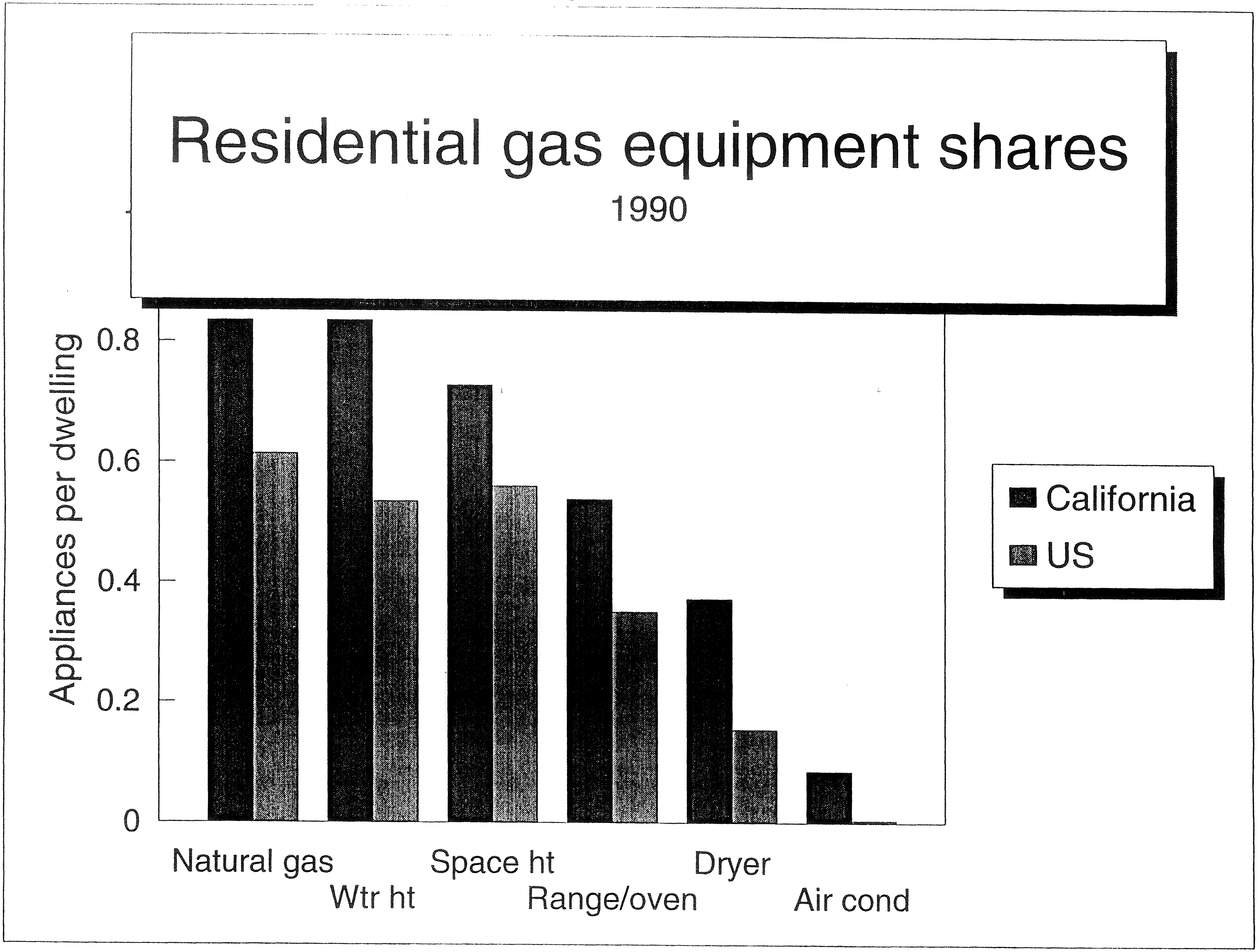
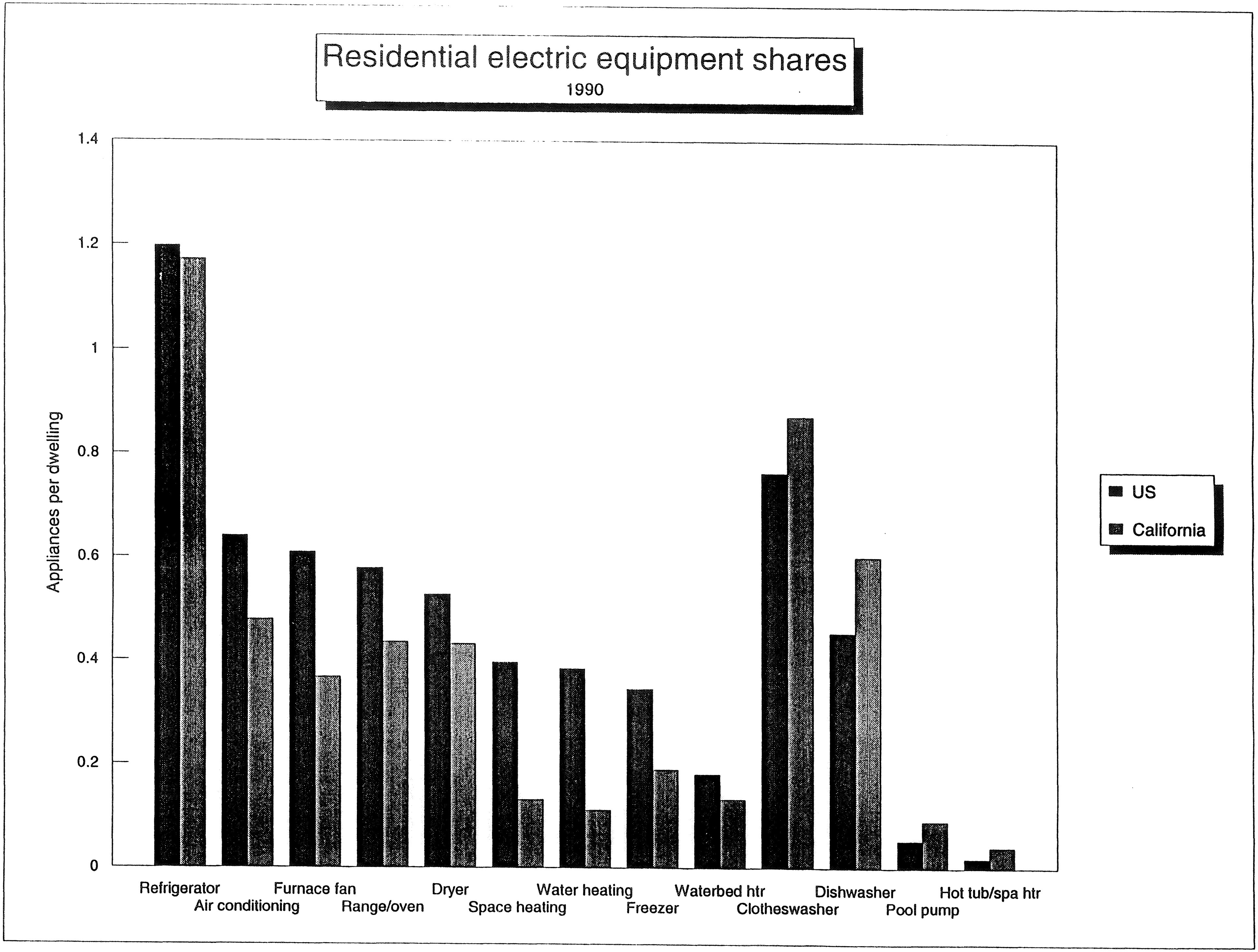

Persons per dwelling unit
3.3
3.1
2.9
2.7
2.5
Persons per dwelling unit
1970
1975
1980
1985
1990
YEAR
CALIFORNIA
USA

Figure 2.3


Residential gas equipment shares
1990
Appliances per dwelling
0.8
0.6
0.4
0.2
0
Natural gas
Wtr ht
Space ht
Range/oven
Dryer
Air cond
California
US

# Figure 2.4



Residential electric equipment shares
1990
Appliances per dwelling
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Refrigerator
Air conditioning
Furnace fan
Range/oven
Dryer
Space heating
Water heating
Freezer
Waterbed htr
Clotheswasher
Dishwasher
Pool pump
Hot tub/spa htr
US
California

Figure 2.5

**Residential Energy Intensities in the US and California**
Space Heating Energy Intensity per Floor Area

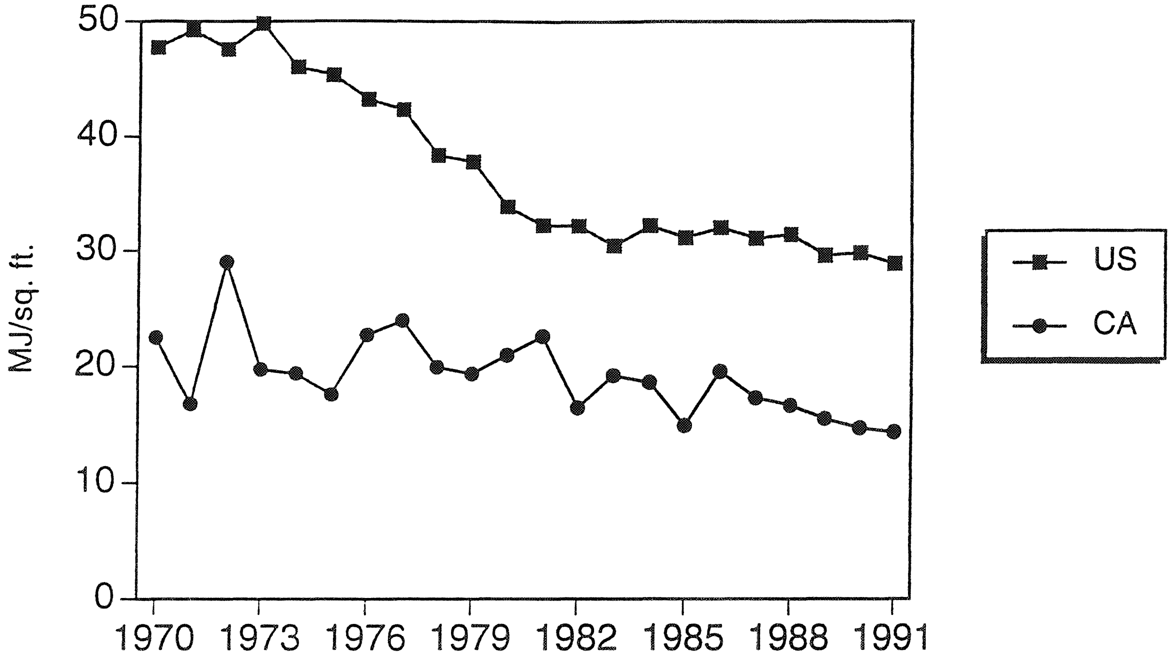



Figure 2.6

**Residential Energy Intensities in the US and California**
Space Heating Energy Intensity per Capita and per Dwelling

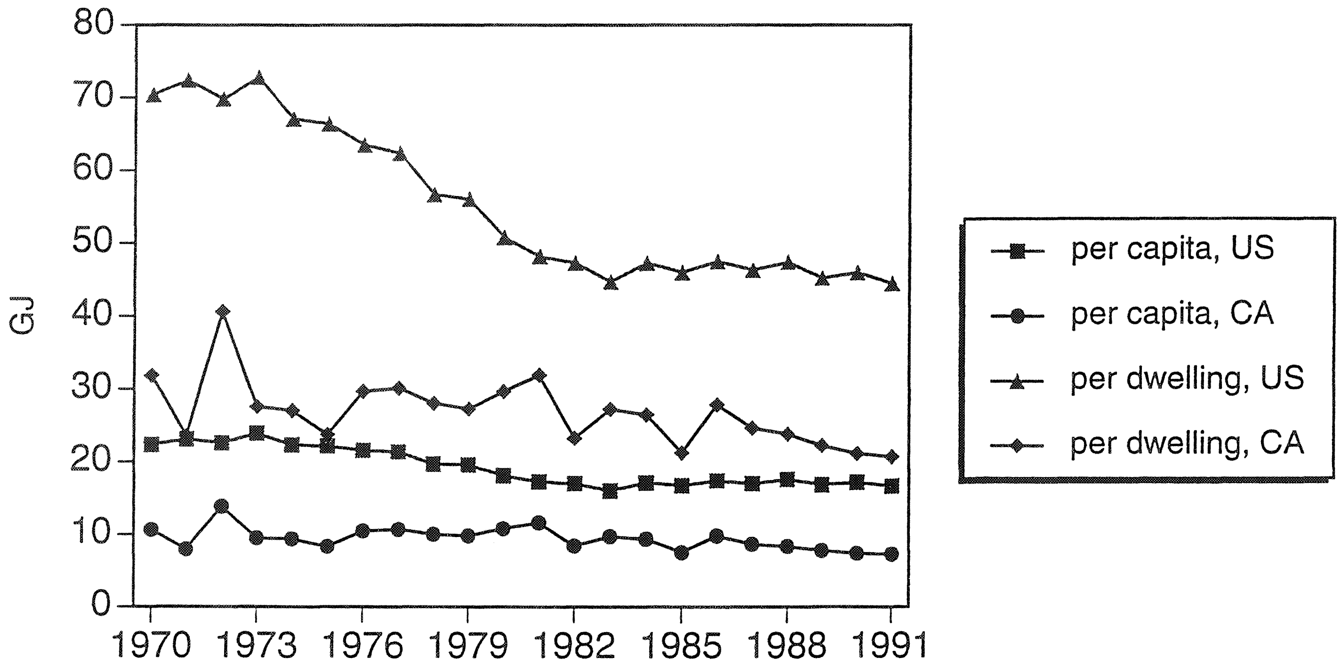


Figure 2.7(a)

**Residential Energy Intensities in the US and California**
Useful Space Heating Intensity per Capita-Degree Day

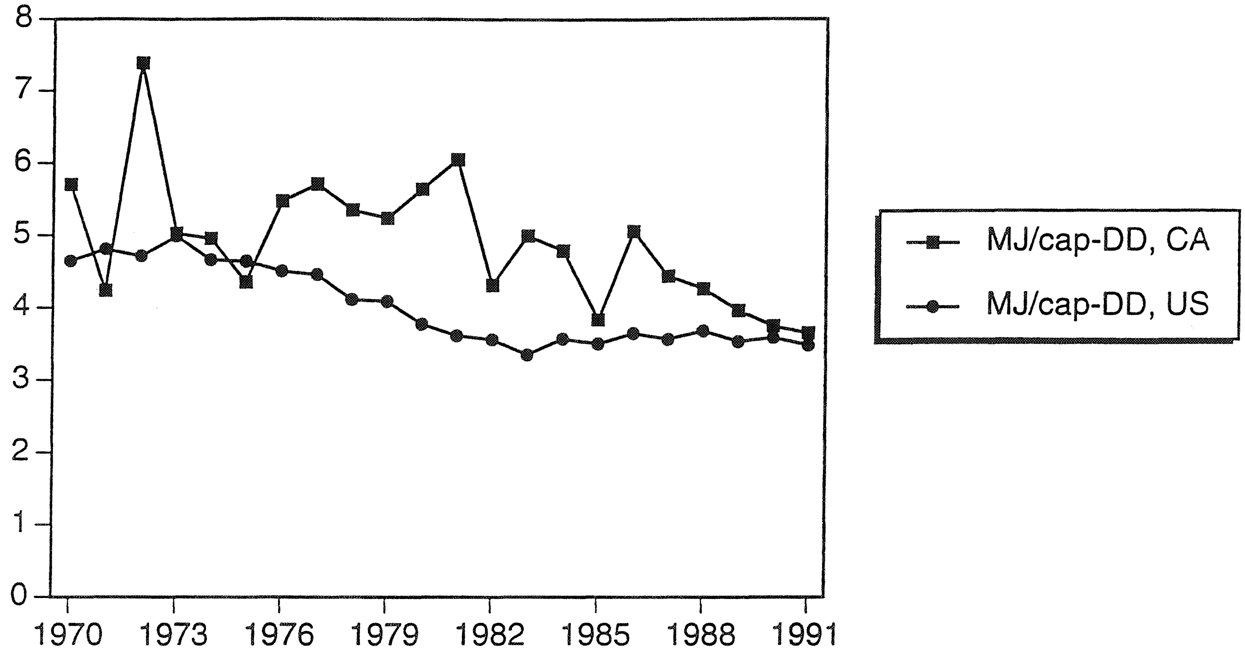



Figure 2.7(b)

**Residential Energy Intensities in the US and California**
Useful Space Heating Intensity per Dwelling-Degree Day

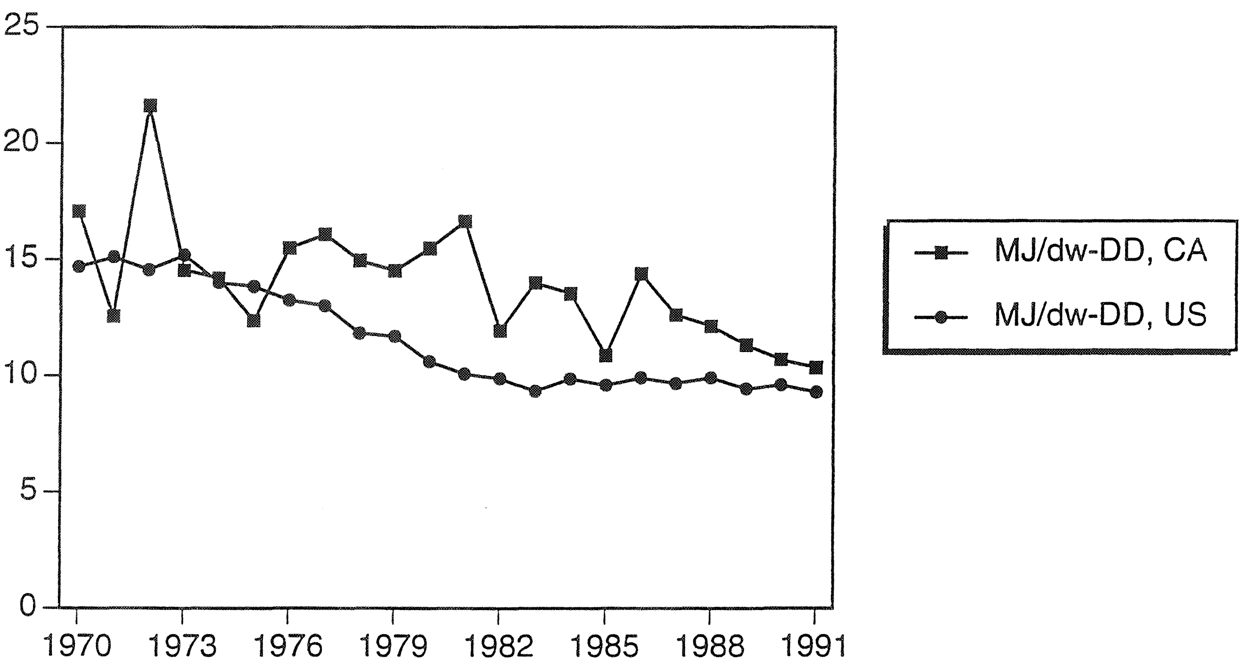


Figure 2.7(c)

**Residential Energy Intensities in the US and California**
Useful Space Heating Intensity per Floor Area-Degree Day

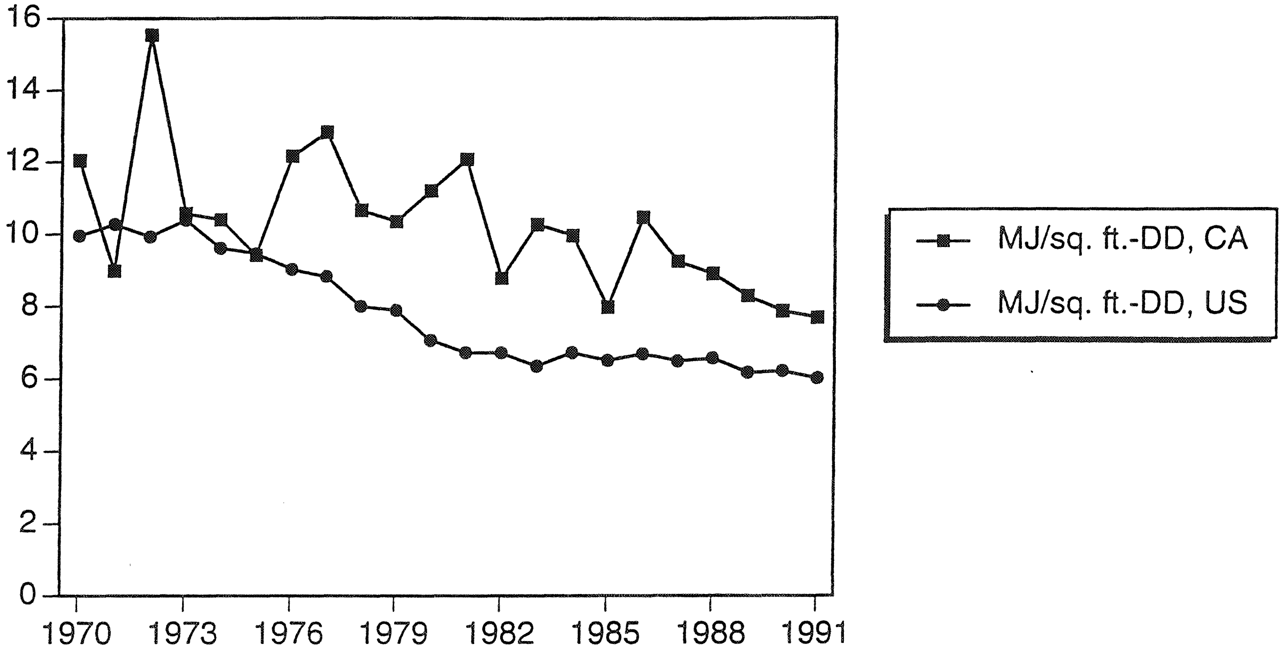


Figure 2.8

**Residential Energy Intensities in the US and California**

Water Heating Energy Intensity per Capita and per Dwelling

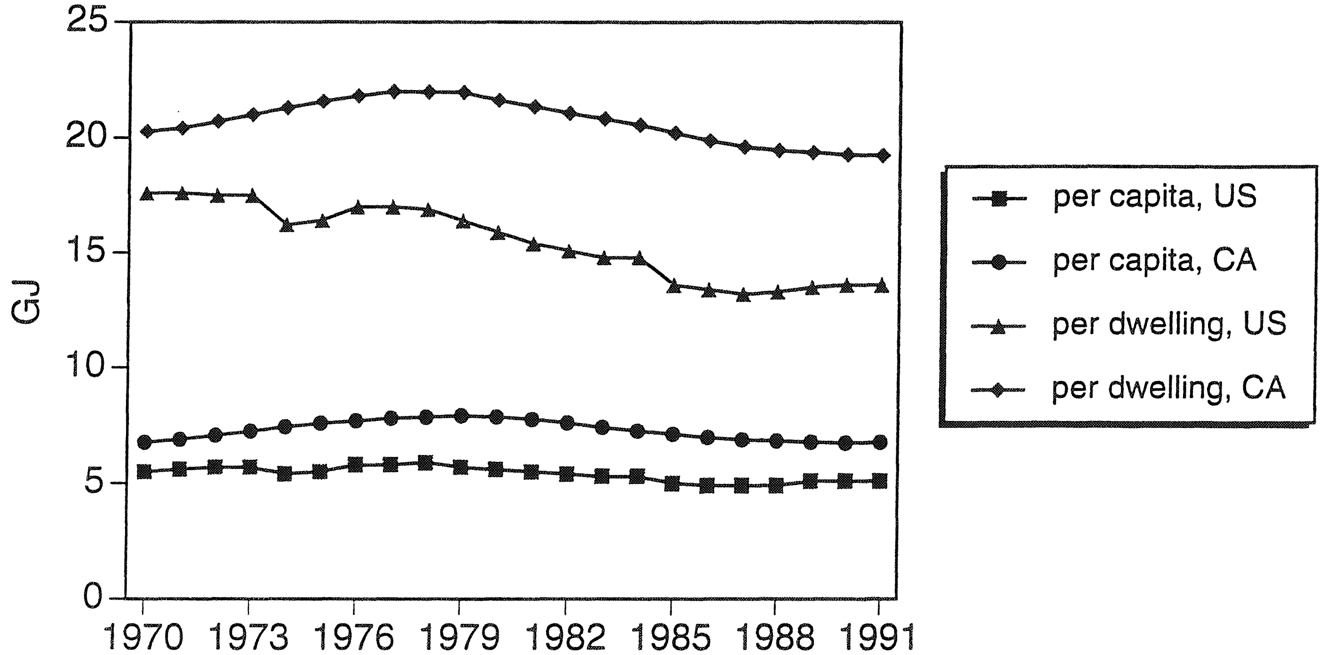
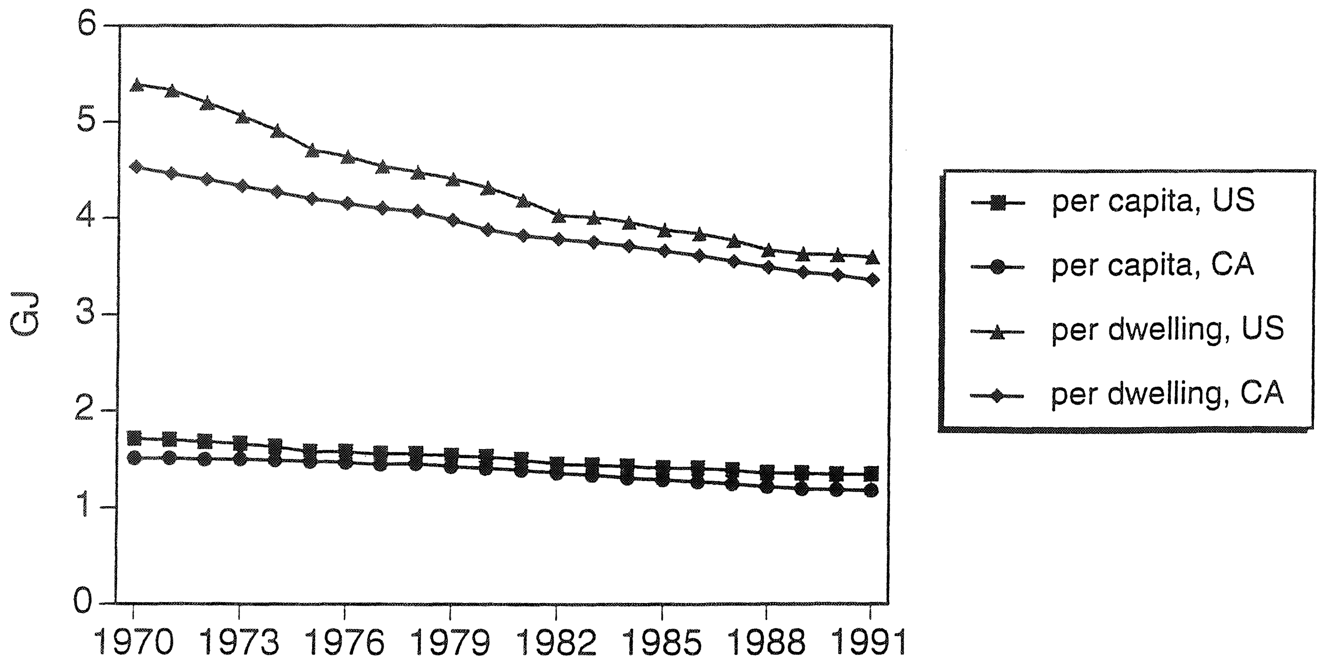



Figure 2.9

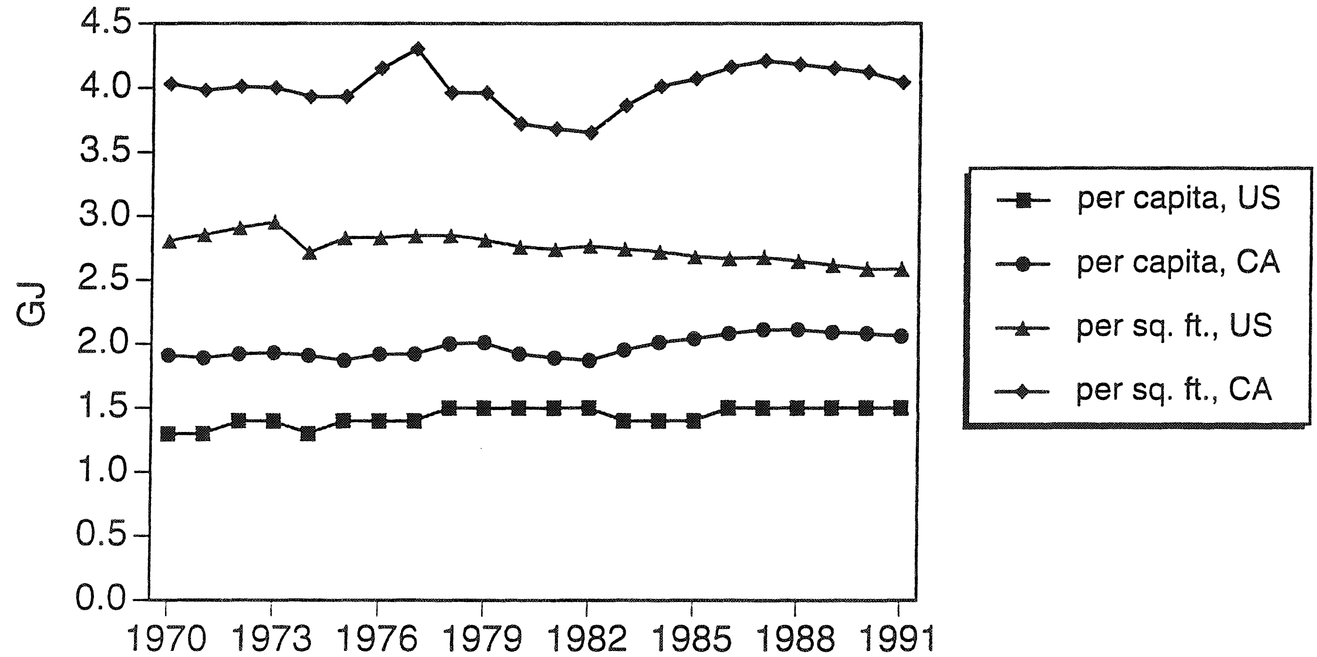
**Residential Energy Intensities in the US and California**

Cooking Energy Intensity per Capita and per Dwelling



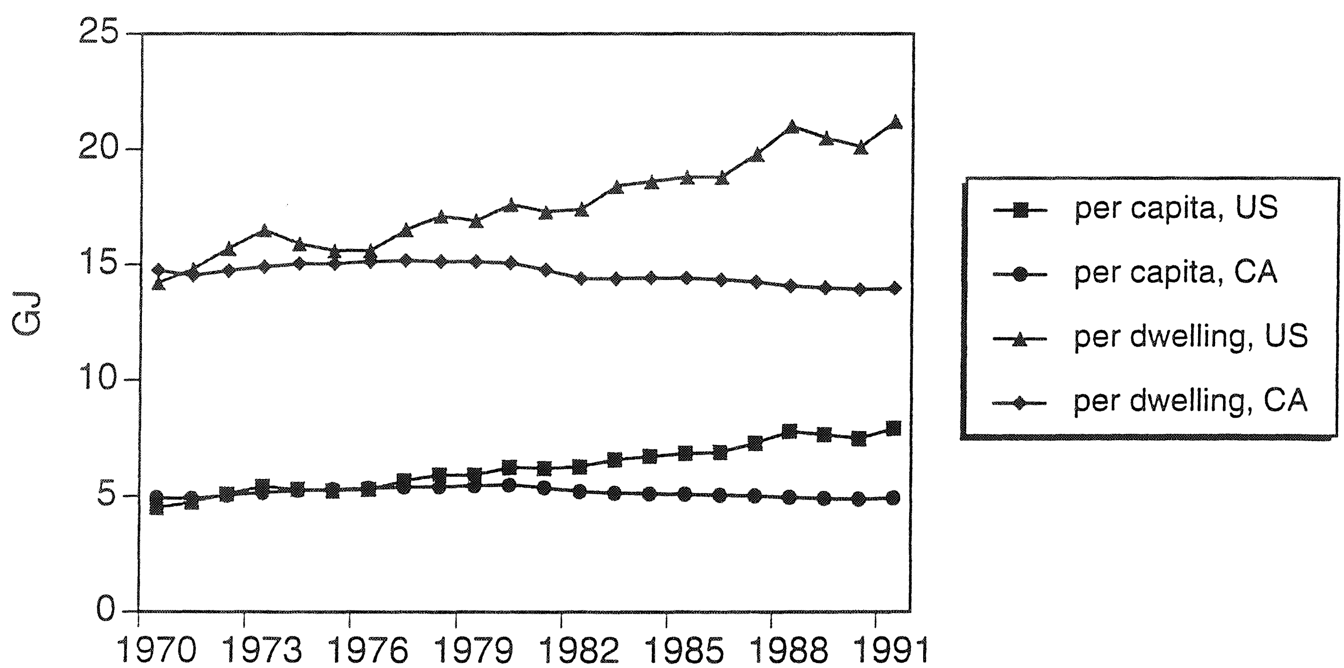
## Figure 2.10

**Residential Energy Intensities in the US and California**
Lighting Energy Intensity per Capita and per Floor Area




## Figure 2.11

**Residential Energy Intensities in the US and California**
Appliance Energy Intensity per Capita and per Dwelling



# 3. SERVICE (COMMERCIAL) SECTOR

## 3.1. Definition of Sector

The commercial sector is defined as in the CEC forecasting model, including the following building activities: large offices, small offices, hotel/motels, warehouses, retail stores, food stores, university/colleges, restaurants, elementary schools, hospitals, and miscellaneous.

## 3.2. Data Sources

The California electricity and natural gas data were provided by CEC staff from databases associated with the CEC forecasting model.

For the U.S. service sector, two data sets are used: SEDS and CBECS. Definitional problems arise for this sector, since some commercial customers (as identified by utility accounting) are actually multifamily dwellings, e.g., master-metered apartment houses.[9]

## 3.3. Aggregate Trends

California uses a smaller share of U.S. service sector energy than California's share of U.S. service employees, or commercial floor area (Figure 3.1). Compared to a 16% share of service employees, 10% of commercial floor area, and an 11% share of U.S. population in 1989, California service sector final energy represents 8.7% of U.S. service sector electricity, 5.5-5.9% of natural gas, and 0.6% of oil (Figure 3.2).

The population of California increased 42% from 1975 to 1991. Service sector employees increased by 53%, while service sector floor area increased 59%. Service sector electricity consumption increased 67%, and natural gas consumption increased 17%.

Value added increased 77% (in 1982$), so electricity per dollar value added decreased 4%, primary energy per dollar value added decreased 9%, and final energy per dollar value added decreased 16%.

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[9] In comparing the sources of US data, we have identified some unresolved inconsistencies. These are minor for electricity, but may be important for natural gas. This complicates our attempt to compare California service sector energy consumption and intensities to those of the US. In this report, we compare to the SEDS data. In our treatment of SEDS data, we made a correction, transferring some oil from commercial accounts to multifamily residential. No correction was attempted for electricity or natural gas.

There is a clear difference between the time trend for electricity and for natural gas in the California service sector (Figure 3.4). Electricity per floor area increased 5% from 1975 to 1991, but natural gas consumption per floor area decreased 26%. The explanation for the difference lies in the end-use intensities.

## 3.4. Structural Trends

### 3.4.1. Climate

Important structural differences between California and the U.S. include the much milder heating climate and slightly more severe cooling climate in California compared to the U.S.

### 3.4.2. Building Activity

The definitions of building activities differ, limiting our ability to make some other comparisons directly. California categorizes building activities as large offices, small offices, hotel/motels, warehouses, retail stores, food stores, university/colleges, restaurants, elementary schools, hospitals, and miscellaneous. U.S. studies categorize building activities as assembly, education, food sales, food service, health care, laboratory, lodging, mercantile and service, office, parking garage, public order and safety, warehouse, and other.

Figure 3.5 shows California service sector final energy according to building activity. For California, large offices (21%) and "miscellaneous" (19%) have the greatest shares of total final energy. This resembles the pattern for the U.S., where offices and "mercantile and services" have the largest shares.

## 3.5. Fuel Mix

Nearly 60% of California's 1989 commercial sector final energy is electricity, and 39% is natural gas, with 1% oil (Figure 3.3). U.S. fuel shares for the commercial sector in 1989 are 48% electricity, 36% natural gas, 6% oil, and 10% district heat.

## 3.6. Intensity Trends

Total final energy (combining electricity, natural gas, and oil) is disaggregated into end-uses. The disaggregation for California is from the CEC forecasting model database; for the U.S., CBECS is used. For electricity in the California service sector, indoor lighting is the dominant end-use (39%, see Figure 3.6). For natural gas, "other" and space heat each capture about 40% (see Figure 3.7). Compared to the U.S., California final energy by end-use shows that space heating, water heating, and office equipment have lower shares, while space cooling, ventilation, and refrigeration are more important in

California than in the U.S. For the U.S., space heating is the end-use consuming the most energy, while for California, indoor lighting is the largest end-use (Figure 3.8).

### 3.6.1. Lighting Intensity

Across building types, declines in lighting intensity (MJ/sq. ft.) were observed from 1975 to 1993: offices (-14%), schools (-12%), and retail stores (-17%) (see Figure 3.9).

### 3.6.2. Space Conditioning Intensity

Gas dominates as the space heating fuel for California. After 1979, intensity of gas space heating declined from 5.46 Kj/(HDD-sq. ft.) in 1979 to 3.86 in 1986,and further to 2.93 in 1993 for offices (Figure 3.10). The decline for gas space heat intensity is 45% from 1976 to 1991; significant declines were observed for schools (23%) and retail stores (33%) also. Similarly, significant declines are observed for electric space heating for offices (-32%, 1976-91) and retail stores (-29%), while schools saw an increase of 2%.

### 3.6.3. Air Conditioning Intensity

In contrast to space heating, intensity of air conditioning increased over time. For offices with electric air conditioning, Kj/(HDD-sq. ft.) increased 39% (Figure 3.11), and for offices with natural gas cooling, intensity increased 31%. Other building types, while showing similar trends to offices with respect to space heating intensities, do not reflect the increase in space cooling intensity. Retail stores shows no change on average from 1976 to 1993, while schools showed a 3% decline in electric cooling intensity. Retail stores cooled by natural gas showed a 28% decline in intensity, while schools showed a 14% decline.

Office equipment electricity consumption increased dramatically, particularly in offices (Figure 3.12), and contributed to the increase in air conditioning intensity. For small offices, office equipment consumed 27% of the total electricity in 1993, and for large offices, 18%. For the entire commercial sector, office equipment is estimated to consume about 8% of total electricity in 1993.

The growth in total cooling for small and large offices from 1876 GWh in 1975 to 4946 GWh in 1993 is 3070 GWh, at the same time that growth in office equipment electricity increased 5386 GWh (from 69 GWh in 1975). As an approximate upper estimate of the significance of this increase in office equipment electricity, if all of the electricity consumed by office equipment represented heat that was removed by electric air conditioning at a COP of 3, this would account for almost 1800 (59%) of the 3070 GWh increase in office air conditioning electricity.

### 3.6.4. Intensity by Building Types

The largest increase in GJ per square foot occurred for small offices - 20% from 1975-91, and large offices saw an increase of 11%. All the other building types experienced a decrease, ranging from 1% (warehouses) to 18% (schools).

## 3.7. Detailed Analysis

The California service sector is growing, both in absolute terms and as a share of the U.S. service sector, as measured by service employees and commercial floor area. In contrast, California's share of U.S. service sector electricity declined from 1979 to 1985, and now lags about 10 years behind the commercial floor area share.

California's mild heating climate is reflected in a disproportionately low share of U.S. gas consumption. Indoor lighting is the largest electricity end-use, and gas space heat and "other" are the largest gas end-uses.

Most building types show a decrease in intensity (GJ/sq. ft.) over time, with the exception of small and large offices. In office buildings, intensity declined over time for lighting and space heating (electric and gas). However, a large increase occurred in electricity consumed for office equipment and air conditioning. We surmise that the large increase in energy for office equipment contributed to heating the office and thus to the increase in air conditioning energy.

### 3.7.1. Building standards

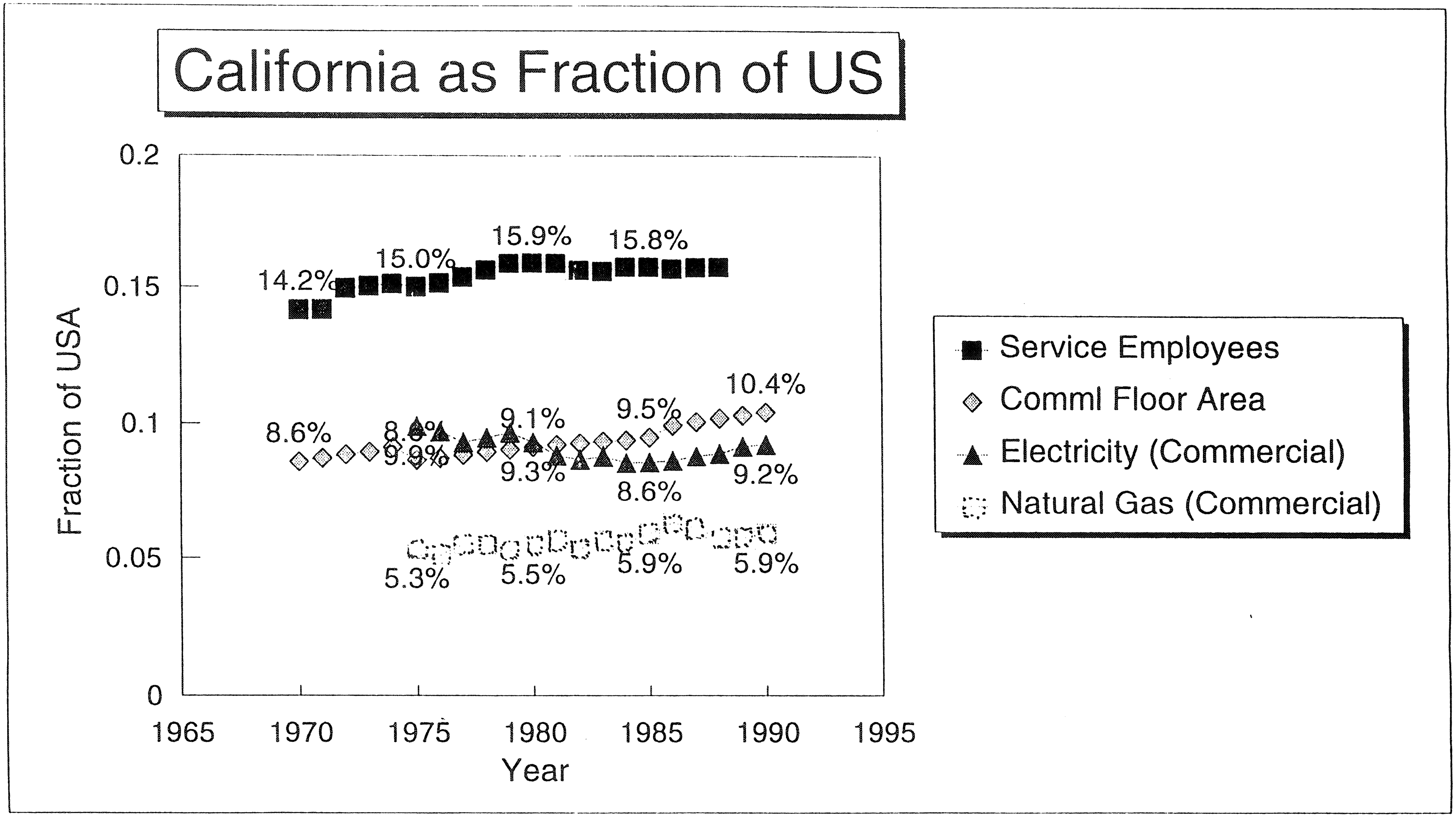
California enacted building standards affecting new construction from 1978 on. A Pacific Gas and Electric company on-site survey in 1986 showed large changes in wall and ceiling insulation and average light density for commercial buildings constructed in or after 1978, compared to prior construction.

A recent CEC staff report concludes that California's energy efficiency standards for nonresidential buildings, while differing slightly in scope, already met or exceeded the requirements of ASHRAE Standard 90.1-1989, as required by the national Energy Policy Act of 1992.

### 3.7.2 Utility programs

In this report, we made no attempt to evaluate the impacts of utility programs on the commercial sector. Our focus was on the aggregate indicators. More data, and more effort, are needed to estimate the impacts of utility programs.

Figure 3.1



California as Fraction of US
0.2
0.15
0.1
0.05
0
Fraction of USA
1965
1970
1975
1980
1985
1990
1995
Year
14.2%
15.0%
15.9%
15.8%
8.6%
9.1%
9.5%
10.4%
9.3%
8.6%
9.2%
5.3%
5.5%
5.9%
5.9%
Service Employees
Comml Floor Area
Electricity (Commercial)
Natural Gas (Commercial)

Figure 3.2

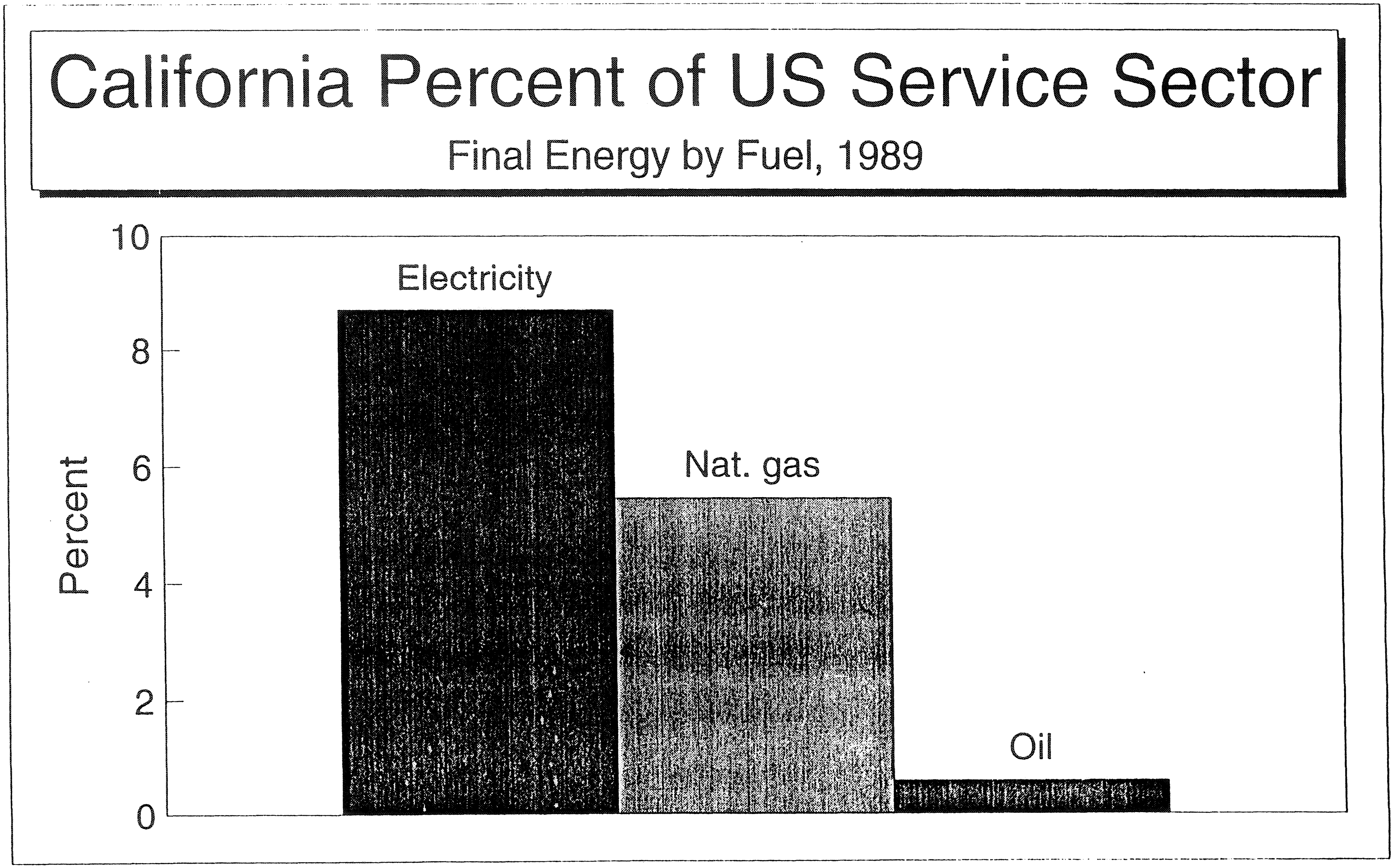

California Percent of US Service Sector
Final Energy by Fuel, 1989
10
8
6
4
2
0
Percent
Electricity
Nat. gas
Oil

Figure 3.3

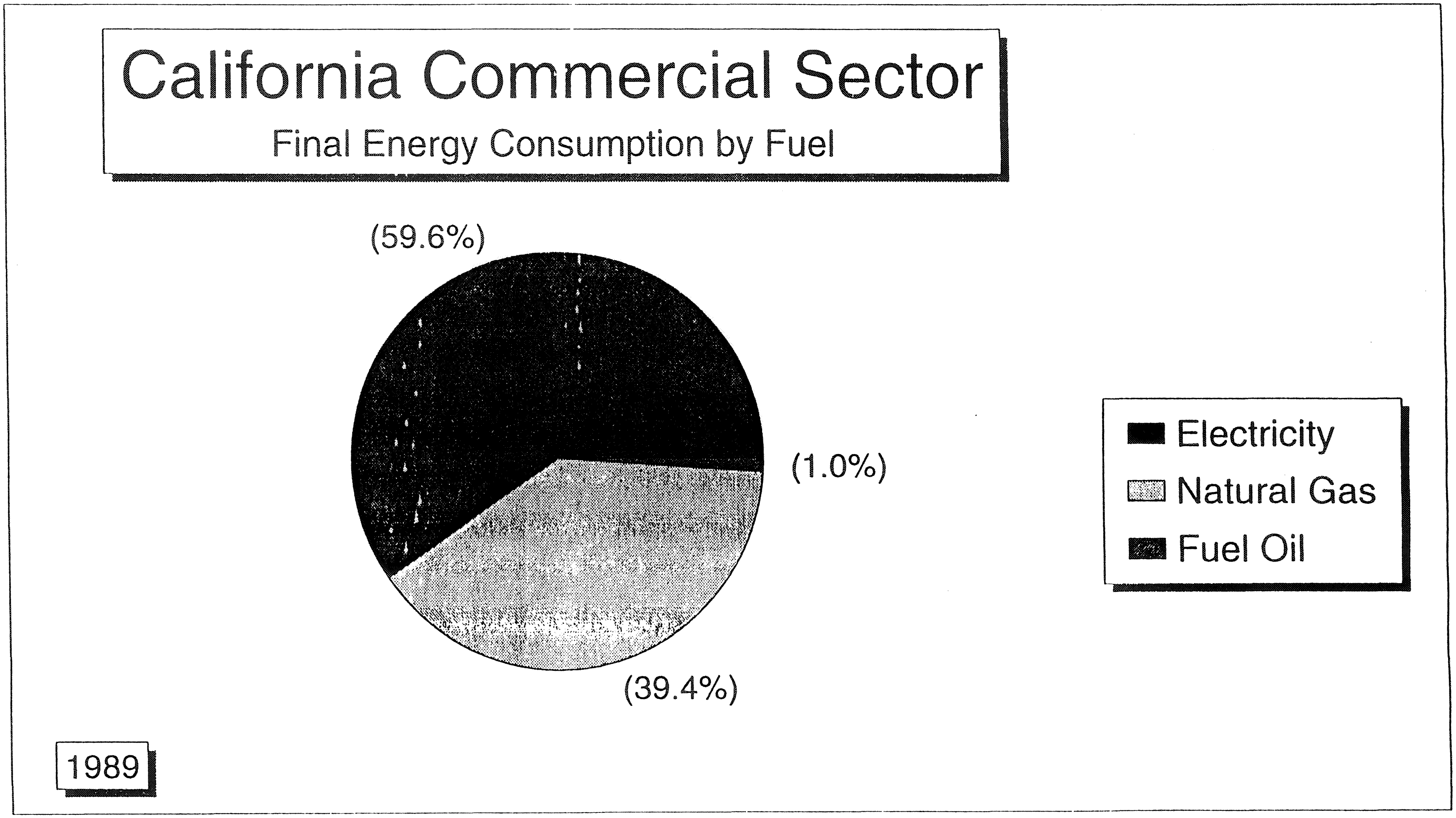
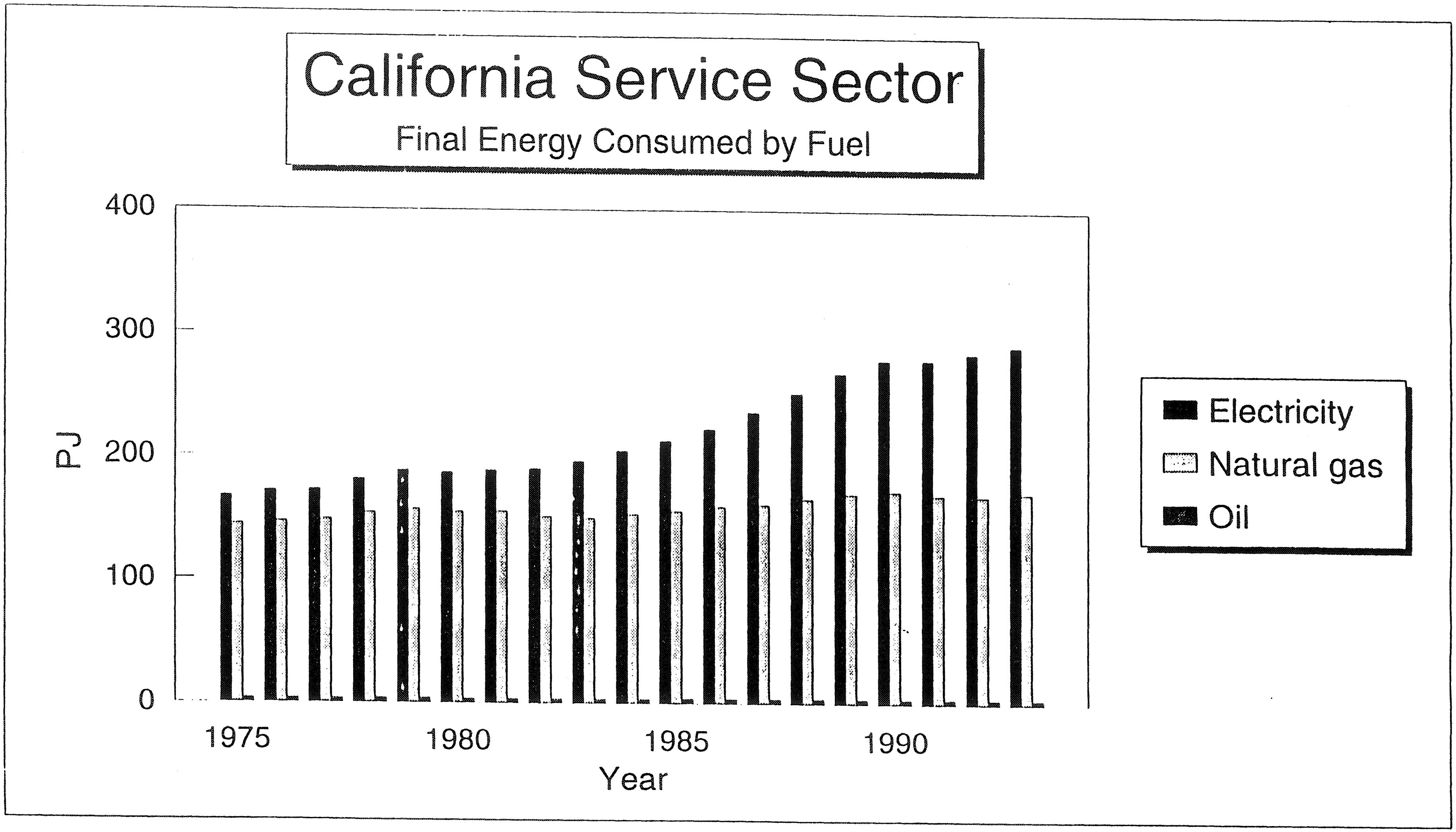
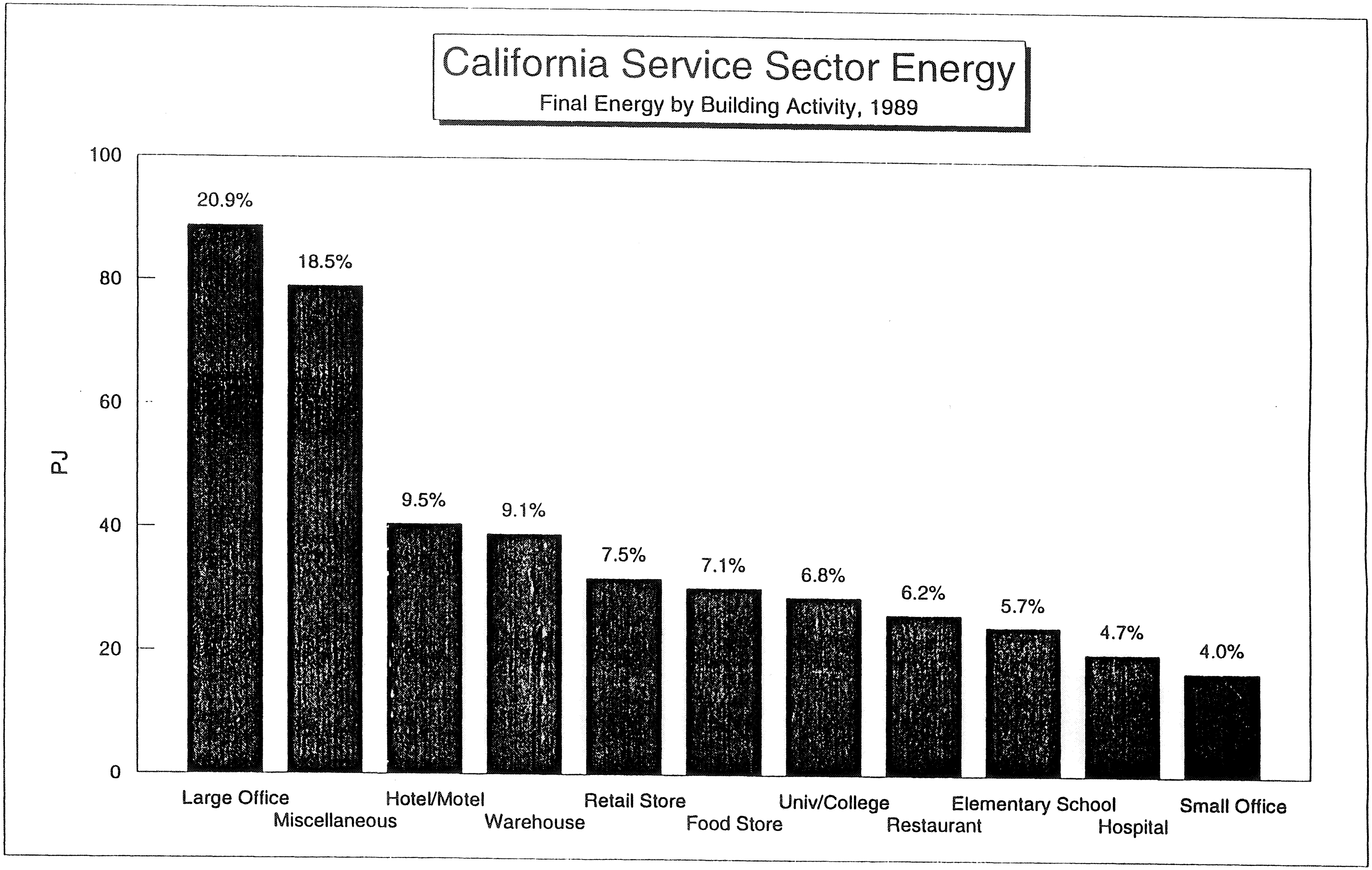

California Commercial Sector
Final Energy Consumption by Fuel
(59.6%)
(1.0%)
(39.4%)
Electricity
Natural Gas
Fuel Oil
1989

Figure 3.4



California Service Sector
Final Energy Consumed by Fuel
400
300
200
100
0
PJ
1975
1980
1985
1990
Year
Electricity
Natural gas
Oil

Figure 3.5



California Service Sector Energy
Final Energy by Building Activity, 1989
100
80
60
40
20
0
PJ
20.9%
18.5%
9.5%
9.1%
7.5%
7.1%
6.8%
6.2%
5.7%
4.7%
4.0%
Large Office
Miscellaneous
Hotel/Motel
Warehouse
Retail Store
Food Store
Univ/College
Restaurant
Elementary School
Hospital
Small Office

# Figure 3.6

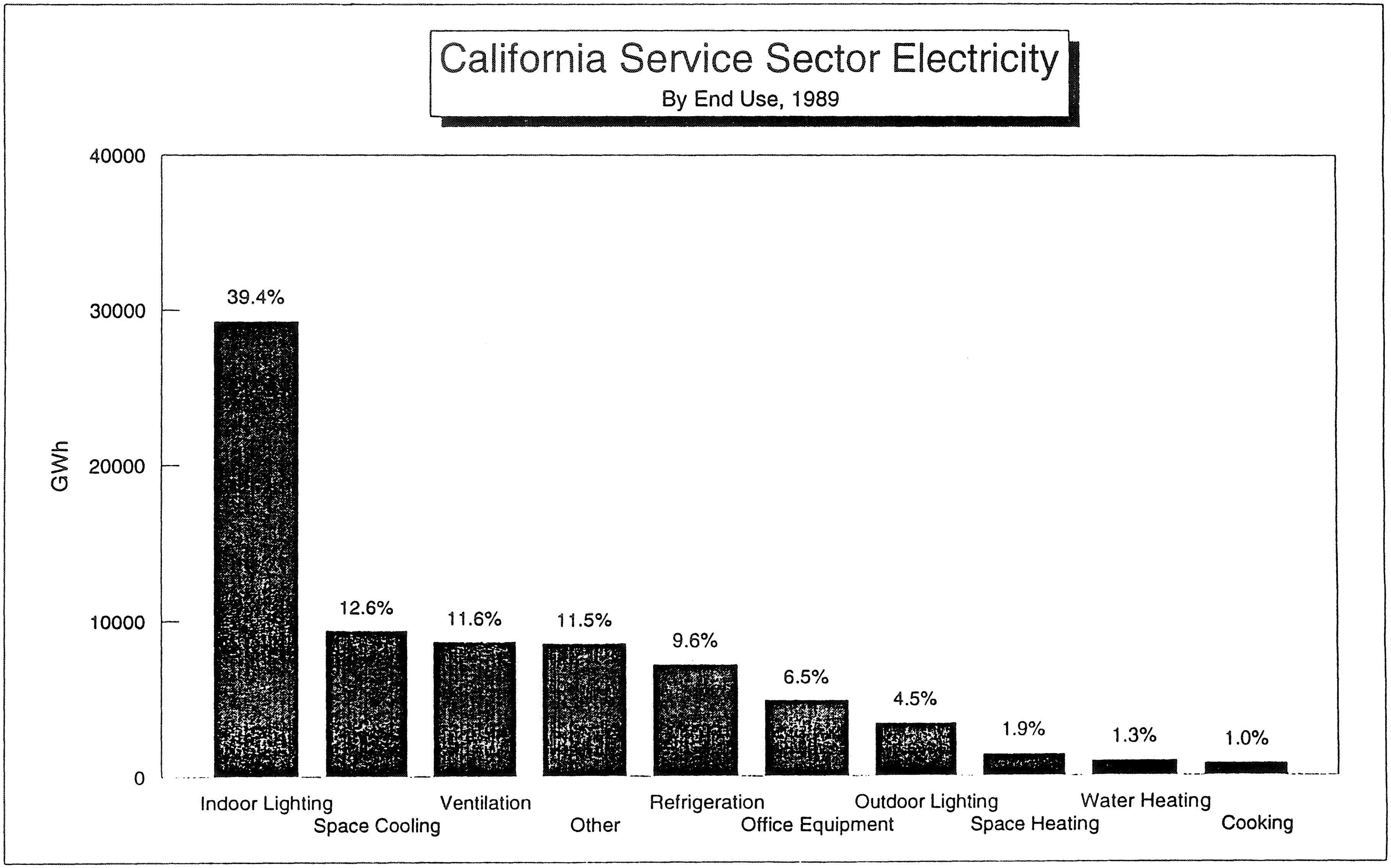

California Service Sector Electricity
By End Use, 1989
GWh
40000
30000
20000
10000
0
39.4%
12.6%
11.6%
11.5%
9.6%
6.5%
4.5%
1.9%
1.3%
1.0%
Indoor Lighting
Space Cooling
Ventilation
Other
Refrigeration
Office Equipment
Outdoor Lighting
Space Heating
Water Heating
Cooking

Figure 3.7

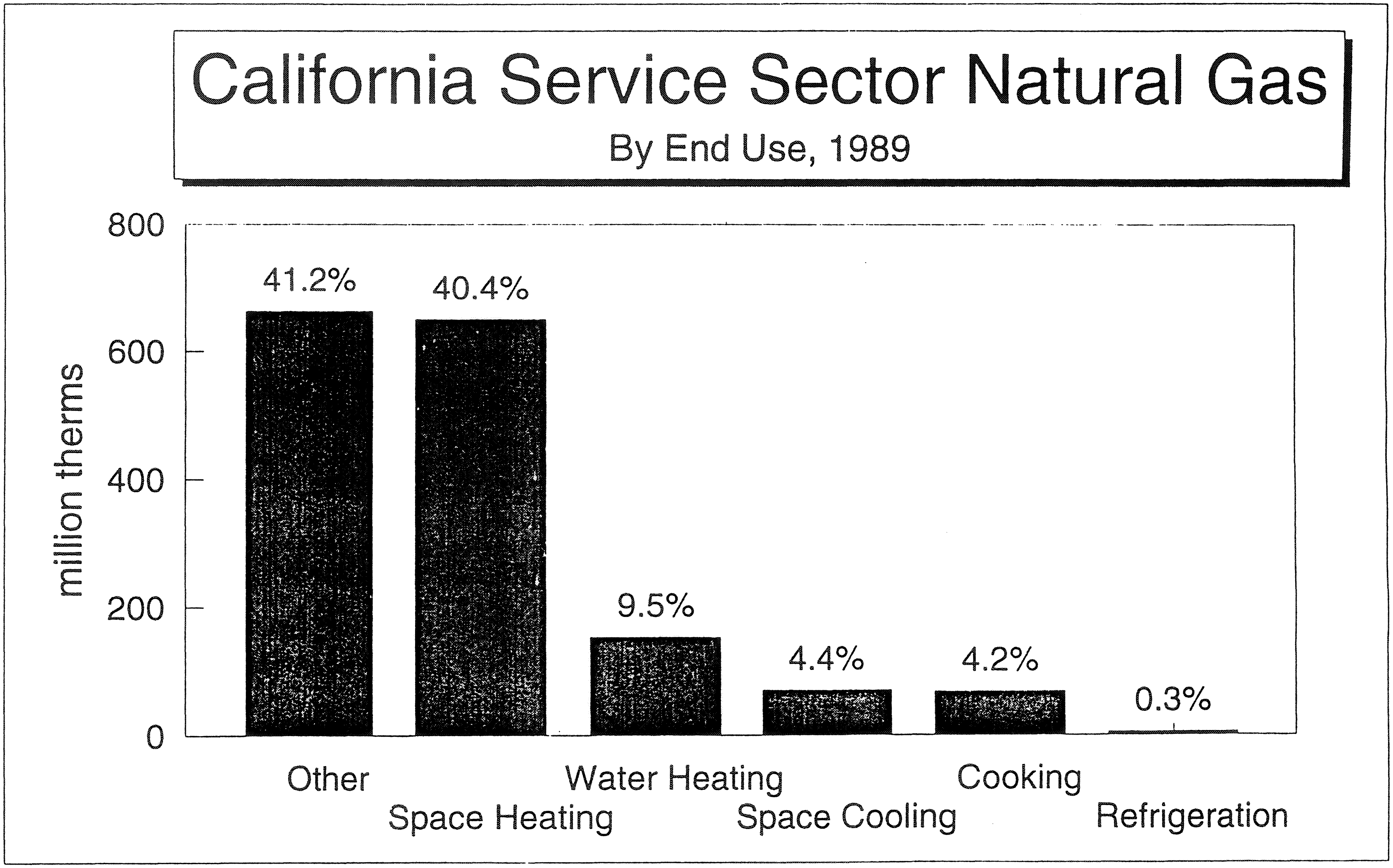
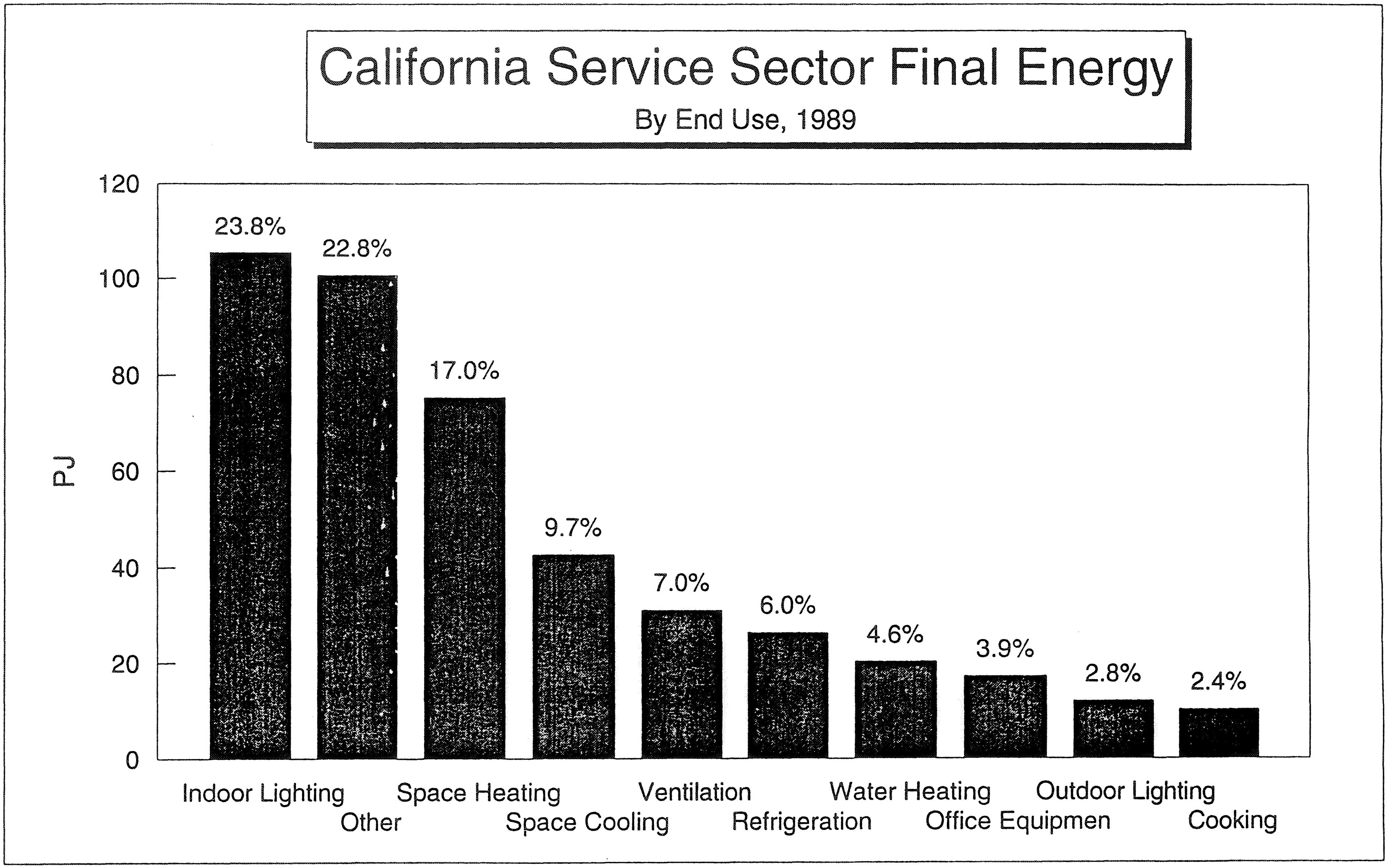
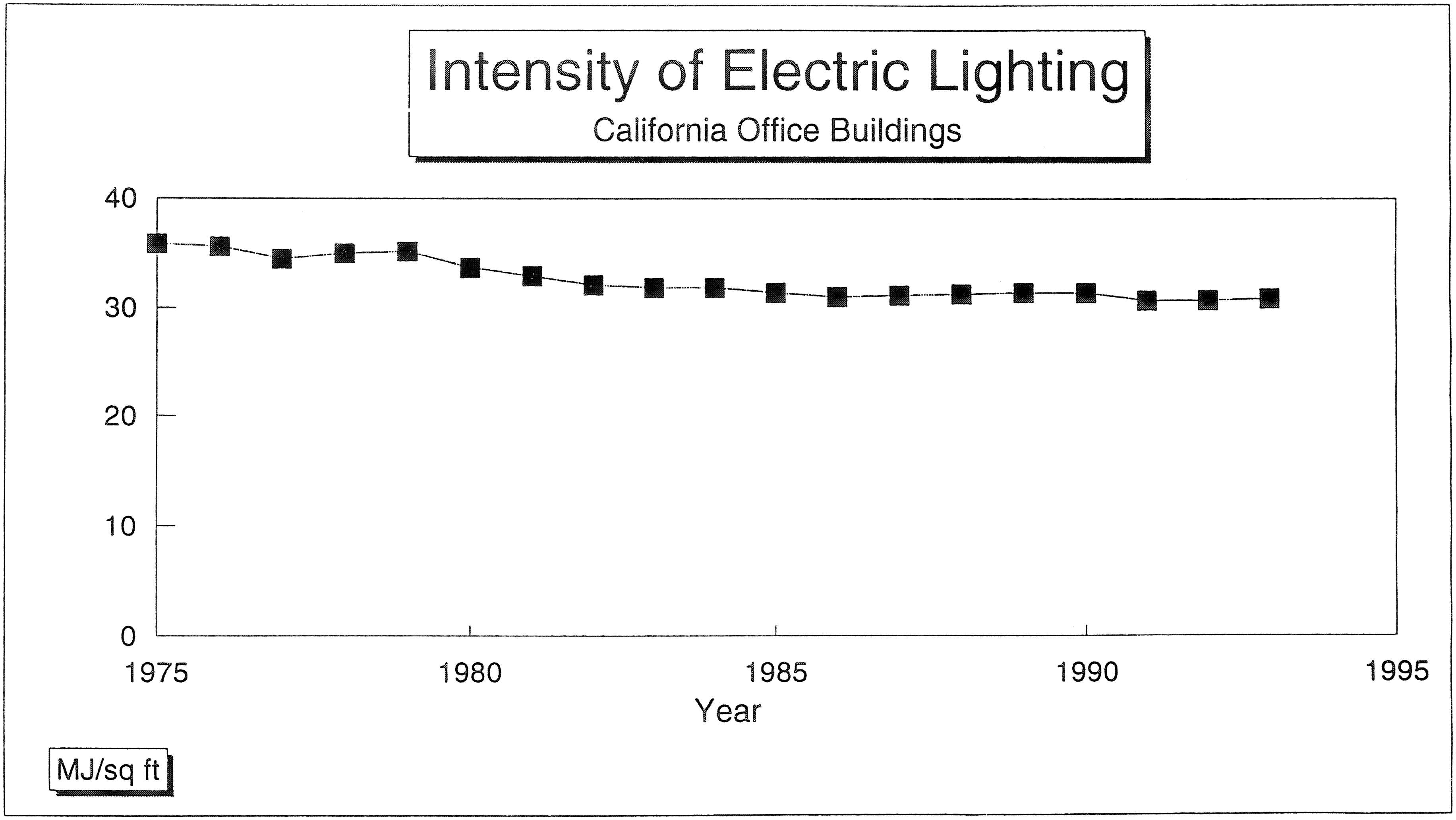

California Service Sector Natural Gas
By End Use, 1989
800
600
400
200
0
million therms
41.2%
40.4%
9.5%
4.4%
4.2%
0.3%
Other
Space Heating
Water Heating
Space Cooling
Cooking
Refrigeration

Figure 3.8



California Service Sector Final Energy
By End Use, 1989
120
100
80
60
40
20
0
PJ
23.8%
22.8%
17.0%
9.7%
7.0%
6.0%
4.6%
3.9%
2.8%
2.4%
Indoor Lighting
Other
Space Heating
Space Cooling
Ventilation
Refrigeration
Water Heating
Office Equipmen
Outdoor Lighting
Cooking

Figure 3.9



Intensity of Electric Lighting
California Office Buildings
40
30
20
10
0
1975
1980
1985
1990
1995
Year
MJ/sq ft

Figure 3.10

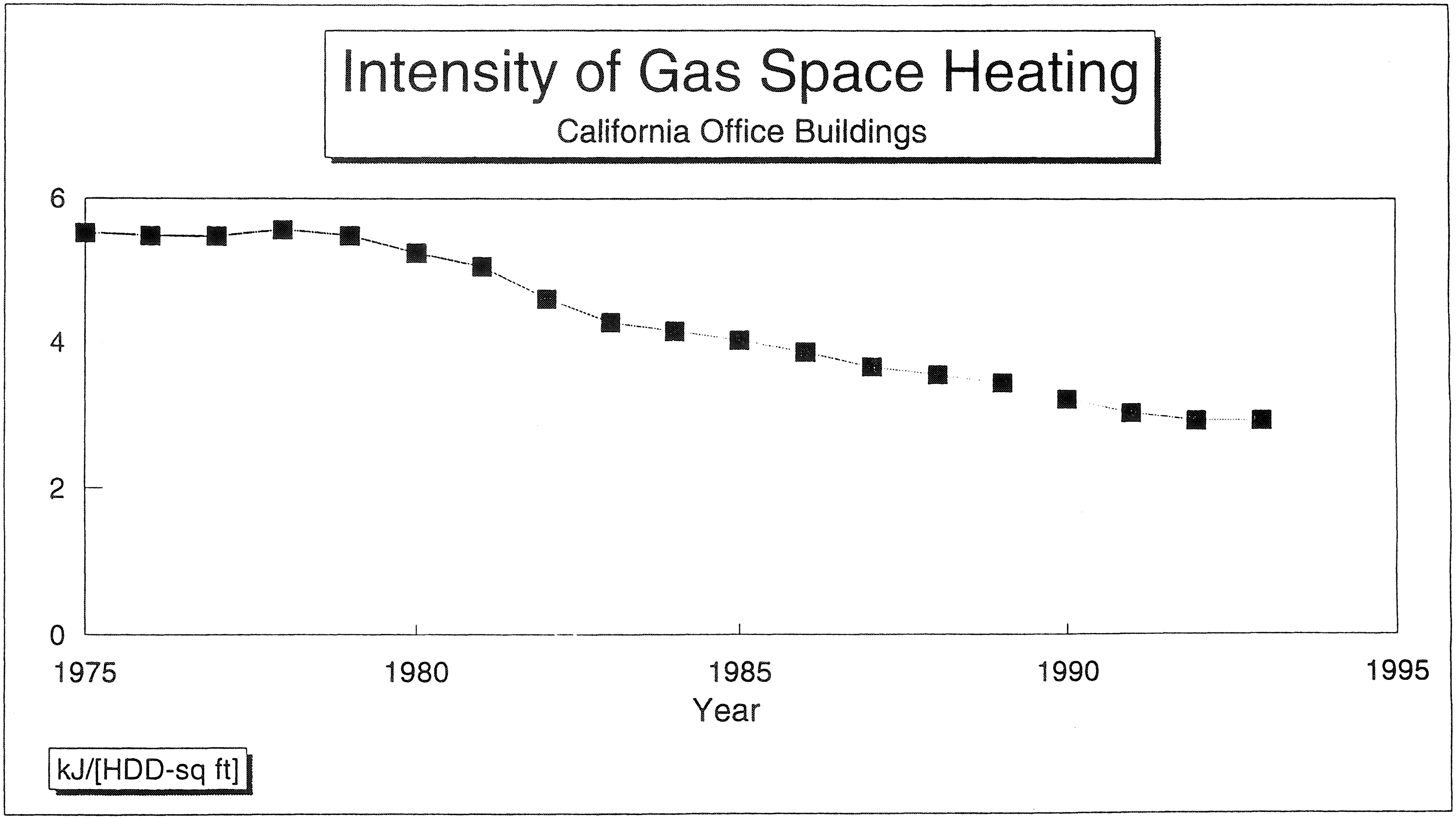
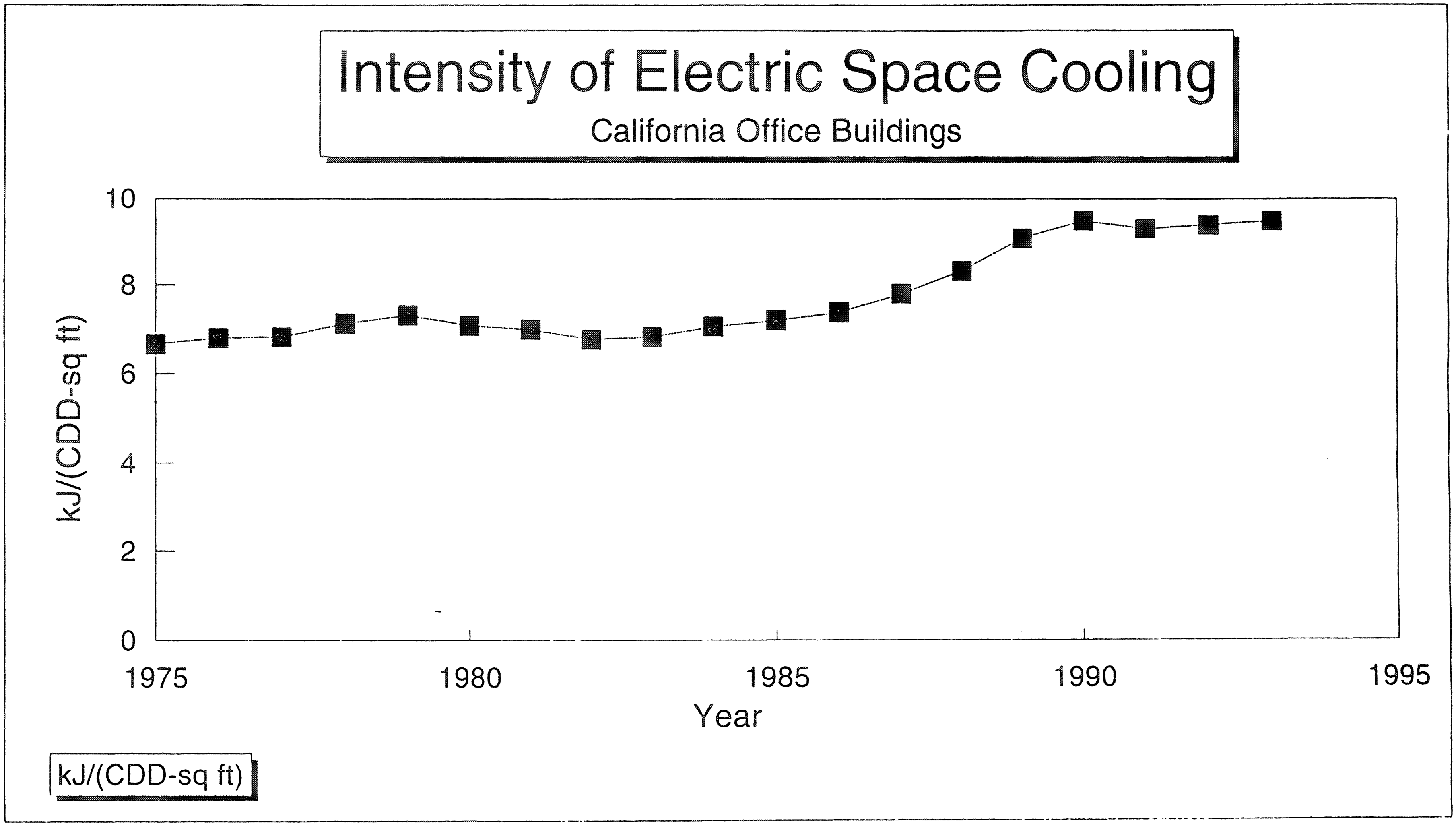
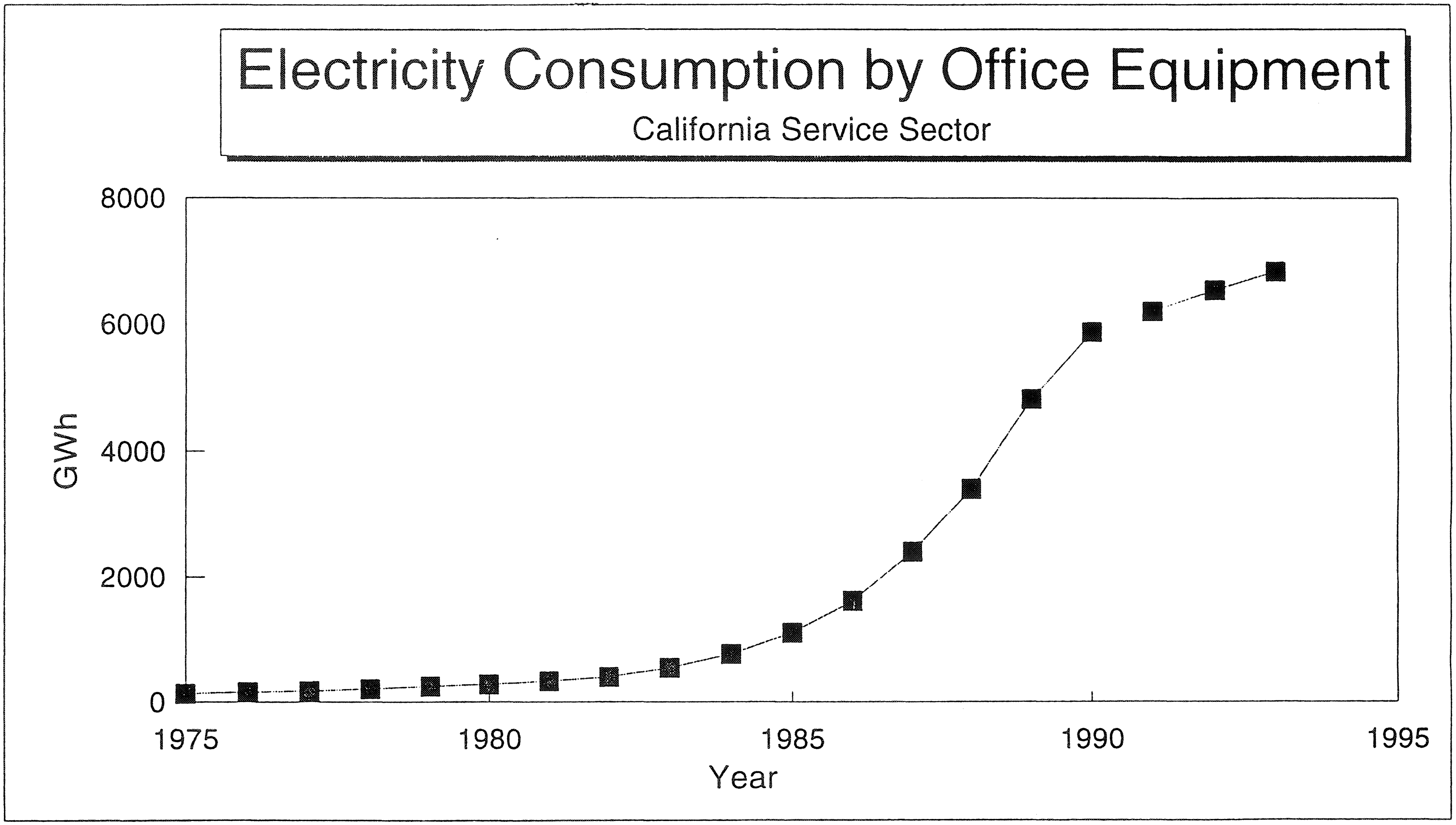

Intensity of Gas Space Heating
California Office Buildings
6
4
2
0
1975
1980
1985
1990
1995
Year
kJ/[HDD-sq ft]

Figure 3.11



Intensity of Electric Space Cooling
California Office Buildings
10
8
6
4
2
0
kJ/(CDD-sq ft)
1975
1980
1985
1990
1995
Year
kJ/(CDD-sq ft)

Figure 3.12



Electricity Consumption by Office Equipment
California Service Sector
8000
6000
4000
2000
0
GWh
1975
1980
1985
1990
1995
Year

# 4. MANUFACTURING

## 4.1. Data Sources

We measured output using real GSP originating in each two-digit sector. The GSP Series came from the California State Finance Department[10] and covered the years 1960-1989 (in 1982$) and 1977-1991 (in 1987$). We chained these together using 1982 as the overlap year and obtained series in both currencies. Ultimately we chose 1982$ for ease of comparison with the U.S. itself.

There are no consistent energy-use data for California's manufacturing sector by subsector. The *Annual Survey of Manufacturers* collected data on purchased energy and electricity through 1981, when this effort was discontinued. Most years were available at the 2- or even 3 digit SIC level from the U.S. Department of Commerce. Unfortunately, no data on electricity for 1974 were available. In the end the limitations of the GSP data and consistency between years forced us to use the 2-digit energy data.

CEC itself has collected data from utilities for gas and electricity consumption at the 2 digit SIC level, data which agreed reasonably well with the *Annual Survey of Manufacturers* data. We also found that the CARB collected data on fuel combusted in certain years (including 1981, 1983, 1987, and 1990). These agreed reasonably well with other sources. However, ASM counts only purchased "energy," which excludes most of the "fuel" consumed by refining, namely, the losses in crude oil in that sector. Fortunately, oil (and solids) represent a small part of manufacturing energy use in California, so inaccuracies in the data here have a small impact on our overall conclusions. Figure 4.1 shows our findings for the years they are available.

Manufacturing energy use for U.S. industries is taken from both the *Annual Survey of Manufacturers,* the National Energy Accounts of the U.S. Department of Commerce, and the Manufacturing Energy Consumption Survey of the DOE/Energy Information Administration. Derivation is explained in Schipper, Howarth, and Geller (1990).

## 4.2. The Structure of Manufacturing in California.

Manufacturing, which accounts for around 18% of California's GSP, is not energy intensive. Only 10% of value added is in heavy manufacturing (paper/pulp, primary metals, stone-glass-clay, chemicals, and refining). There is virtually no raw steel or non-ferrous metals production, and little heavy chemicals manufacturing either. On the

[10] Cynthia Palada, private communication.

other hand, California's oil production and location give it an important oil refining sector.

Overall output in manufacturing in California maintained its share of GSP during the entire period we studied, although there were some short-term fluctuations. Figure 4.2 shows that, all else equal, the increase in manufacturing value-added in California caused a significant rise in manufacturing energy use as shown in Figure 4.2 as "activity." The share of energy use in heavy manufacturing fell between 1973 and 1991. If we hold the energy intensities of individual branches constant, the overall shift of production within manufacturing led to a 10% decline in delivered energy between 1978 and 1991 ("Structure" in Fig. 4.2), and a 9% decline in primary energy. Expressed as annual rates of change, these were 0.8% and 0.7% respectively, and had been continuing since 1973, reversing an extremely slight rise in energy intensity that had been occurring in the 1960s.[11]

## 4.3. Energy Intensities in Manufacturing

Energy intensities are measured as the ratio of energy consumed to value added (1982 or 1987$). Figure 4.3 shows energy intensities. Most have fallen steadily since 1974, the first year for which data for fuels are available. Electricity intensities (Figure 4.4) increased for metals, minerals, and paper/pulp but fell for food, chemicals, and the rest of manufacturing, and fell overall.

If we hold the structure of California's manufacturing constant, we find that electricity intensity fell from 1978 to 1990 by 17%, while overall primary or delivered energy intensity fell by 22%. Additionally, changes in the mix of materials and goods produced reduced manufacturing energy use by about 10% and electricity use by 6%. This is shown in Figure 4.2 as the effect labeled "Intensity." Combined with an overall increase in manufacturing output of 57% (also shown as "Activity" in Figure 4.2), these forces led to a net growth in delivered energy to California manufacturing of only 10% and growth of primary energy of only 11%.

## 4.4. Comparison with the U.S.

California differs significantly from the nation. Per capita value added in manufacturing is lower than the U.S. average, $3285 vs $3710 (1982$), so the share of manufacturing in California's GDP is significantly lower, and the share of output in energy-intensive industries is itself significantly lower than in the U.S. as a whole. These differences are

11 This is not shown in Figure 4.2 but evident if we carry the calculation used back to 1962, which can be done with the GSP data we were provided. A similar trend is discernible for the U.S. as a whole. Unfortunately, the first year for which reliable energy use data were available was 1978.

shown as ratios of per capita value added in Figure 4.5. The share of heavy manufacturing in California's output, 10%, is much lower than the 22% that reflects the nation as a whole. The only heavy industries with output comparable to the U.S. as a whole are cement, paper and pulp, and refining.[12] Moreover, we suspect that the structure of California's metals and chemical industries is far less energy intensive than those in the nation as a whole, as California produces virtually no primary metals or heavy (i.e., raw) industrial or organic chemicals.

Energy and electricity intensities in California tend to be lower than in the U.S. Figure 4.6 shows the primary energy intensities of both regions, while Figure 4.7 shows the electricity intensities. Most striking, lower final or primary energy is consumed per 1982$ in all branches. Much of this difference is probably due to differences in product (even at the 2-digit level) noted above. Only in two categories does California have higher electricity intensities.

Thus we have been able to decompose the California-U.S. differences. California has lower output in manufacturing (measured either per capita or as a share of total GDP), a low share of energy intensive products in that output (which would be even lower if we could obtain data from the 3- or 4 digit level classification of production), and lower energy intensities at the 2-digit level of production. Overall, each of these effects alone (shown in "Total") reduce U.S. per capita manufacturing energy use by 25%, and the combined effect accounts for the fact that California's per capita energy use in manufacturing is only 60% of the value in the U.S.

Given all uncertainties, we conclude that energy productivity in California manufacturing is slightly higher than in the U.S. as a whole. The differences in the structure of output are quantitatively more important than differences in energy productivity in reducing California's manufacturing energy use, per capita, relative to the U.S. The changes in energy intensities over time were about the same in both California and the U.S as a whole, reducing energy use about 23% in California and 25% in the U.S. The changes in the structure of manufacturing output reduce energy use by 10.5% in California and 12% in the U.S. as a whole. Given the uncertainties in the energy consumption data for California, we cannot say whether changes in energy prices, efficiency programs, or other factors affected California more than the U.S. or vice versa.

## 4.5. Other (Non-Manufacturing) Industry

[12] Refining is excluded from our analysis because the predominant energy input, crude oil, is not included in the Annual Survey of Manufacturing, which counts only purchased energy.

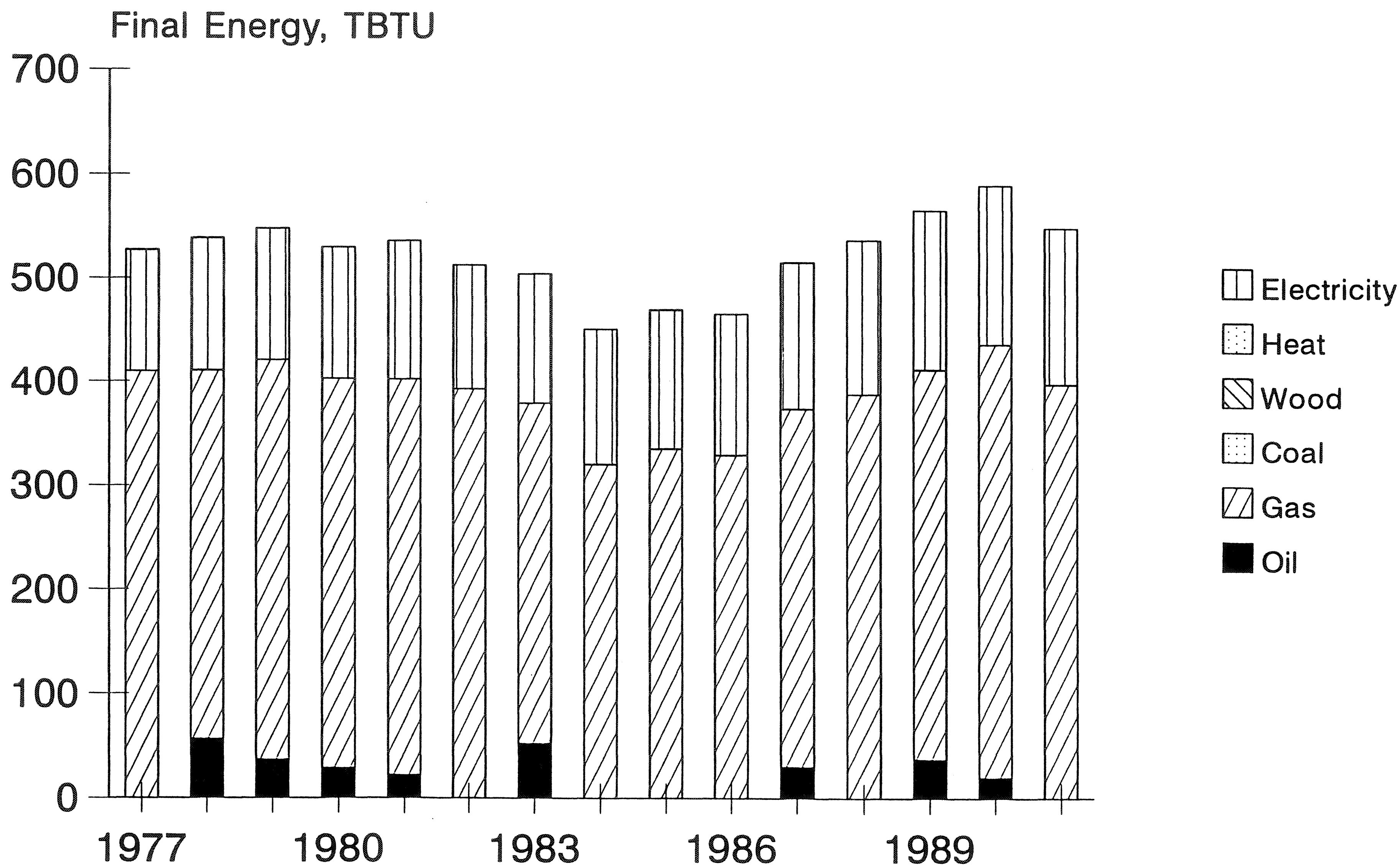
Other Industry contains non-manufacturing activity, and includes agriculture, mining, and construction, as well as other energy losses in the energy sector. As Figure 1.5 shows, this sector accounts for approximately 15% of final or primary energy consumption. As a share of GSP, these industries account for roughly 11% of California's output in 1991, down from 14% in 1970 and about 12% in 1978, reflecting a drop in the importance of mining and utilities in overall production.

Unfortunately, it was almost impossible to get data for energy consumption in agriculture, construction, and mining for California. Industry in the California energy balances (and in SEDS as well) is really a catch-all sector that includes these branches, manufacturing, and miscellaneous losses from the energy sector. A study of energy use in California's agriculture in 1978 (Cervinka et al. 1981) provided many details but did not attempt to account for all uses, and the results can not easily be related to the "other industry" data as we have defined them in this study. We acknowledge that the size of the agriculture sector and its dependence both on liquid fuels and irrigation make it an important energy consumer in California, but could not treat the sector in the limited time available. Worse, the U.S. data for these branches effectively disappeared in 1985, when the National Energy Accounts "give out." This means that for both the U.S. and California, the "other industry" category is almost impossible to define. Consequently, we do not analyze this sector in detail.

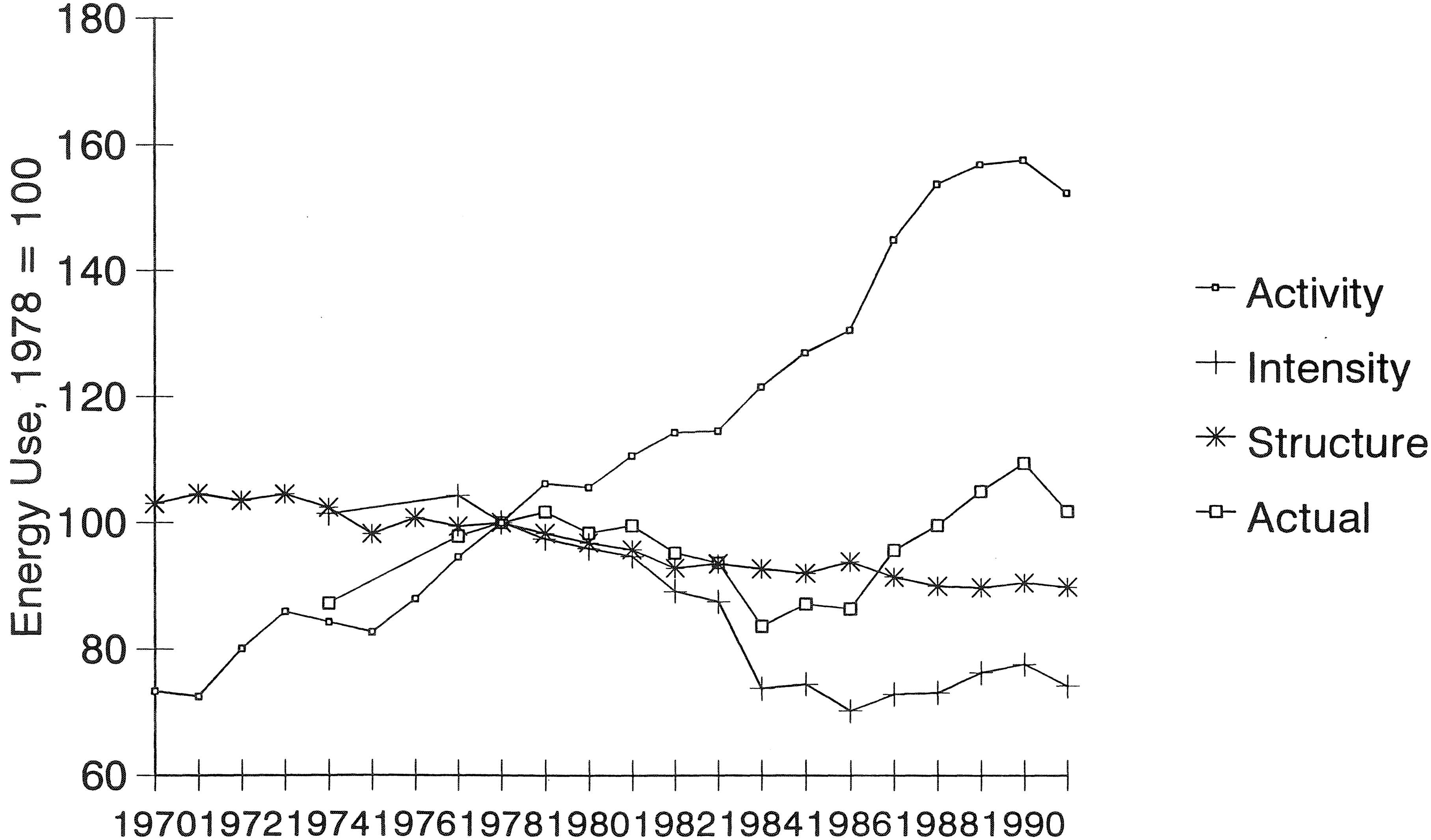
If we compare output and total energy use in the "sector," however we find a trend consistent with manufacturing. Electricity intensity (in kWh/$) increased slightly from 1978 to 1991 (0.3%/year), but final energy intensity fell 1.3%/year.

Figure 4.1

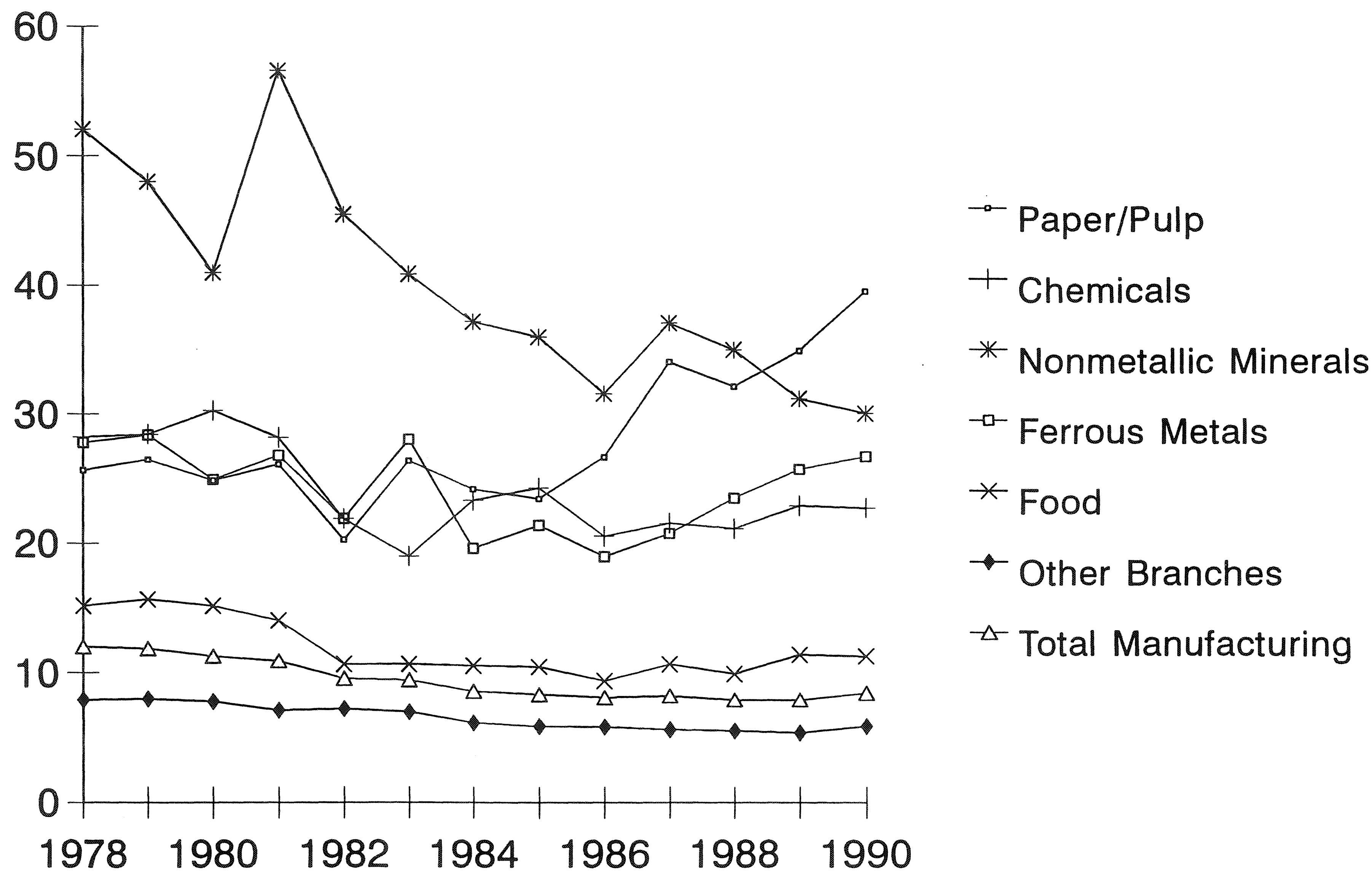
# Energy Use in California's Manufacturing



## Figure 4.2
# Delivered Energy Use in California Manufacturing
# Impact of Changes in Activity, Structure, and Intensity



## Figure 4.3
# Primary Energy Intensities in Calif Manufacturing



## Figure 4.4
# Electricity Intensity of California Manufacturing

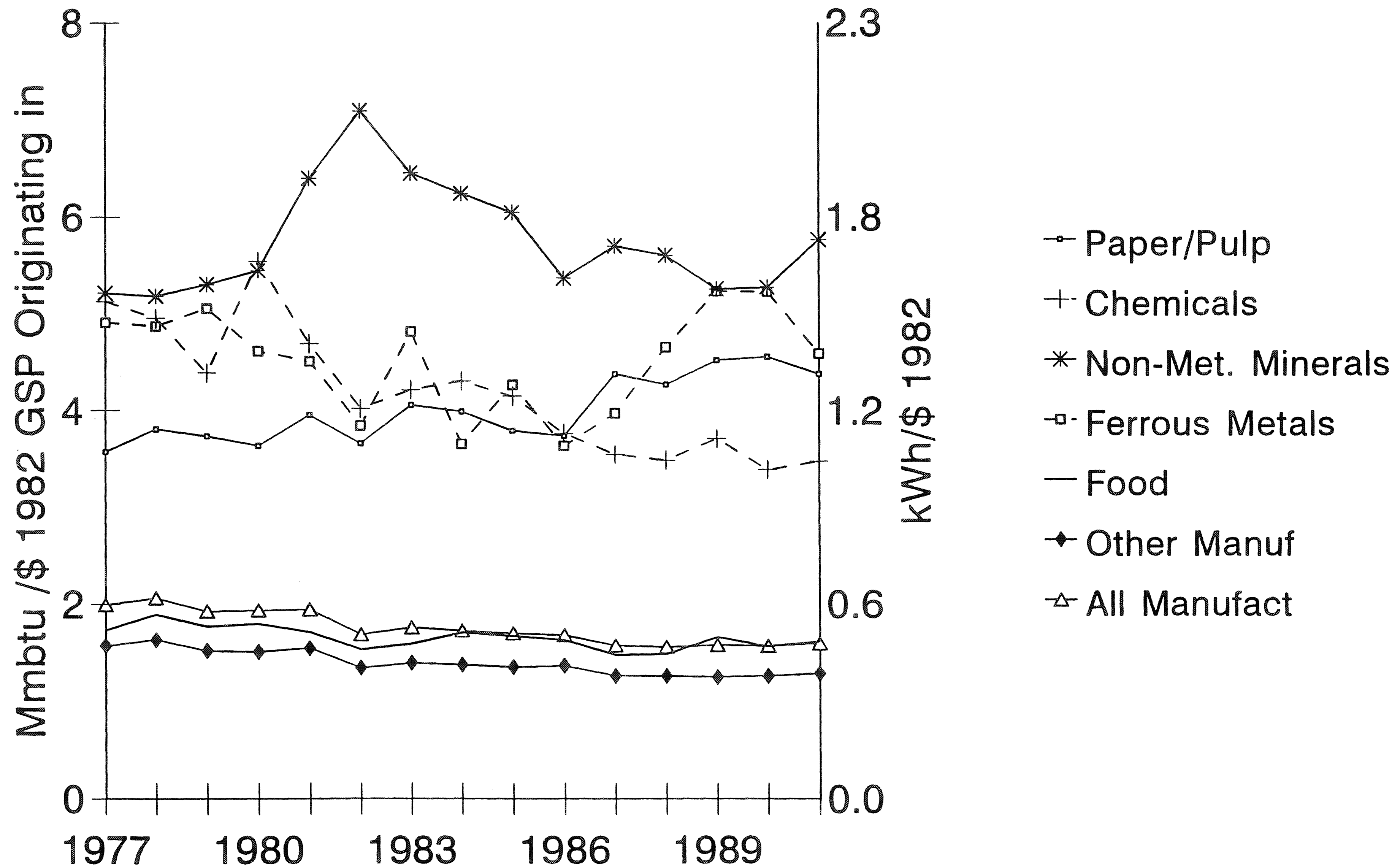


Figure 4.5

# California Manufacturing Structure:

## Per Capita Value Added (1982$) As Fraction of U.S.

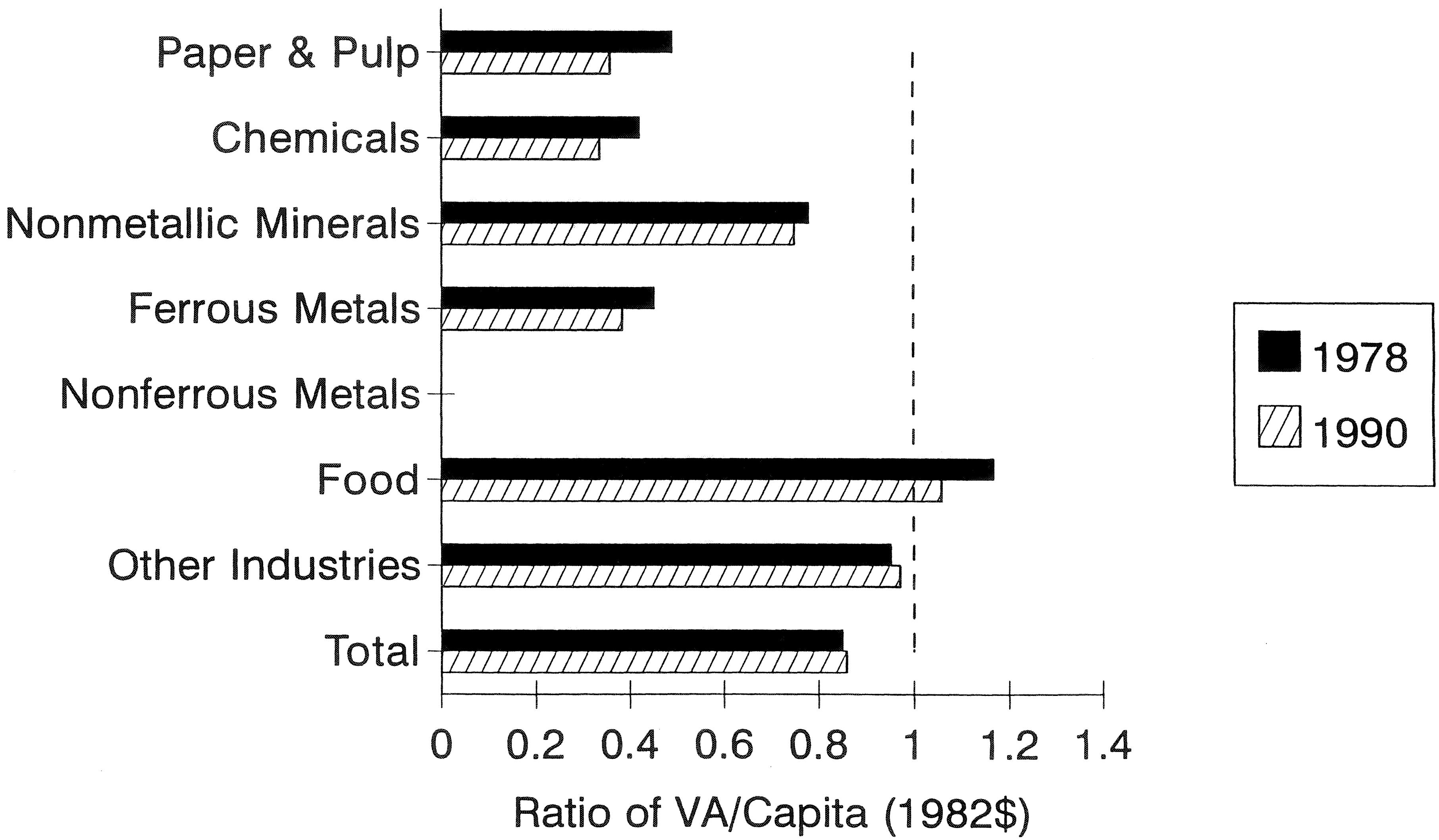
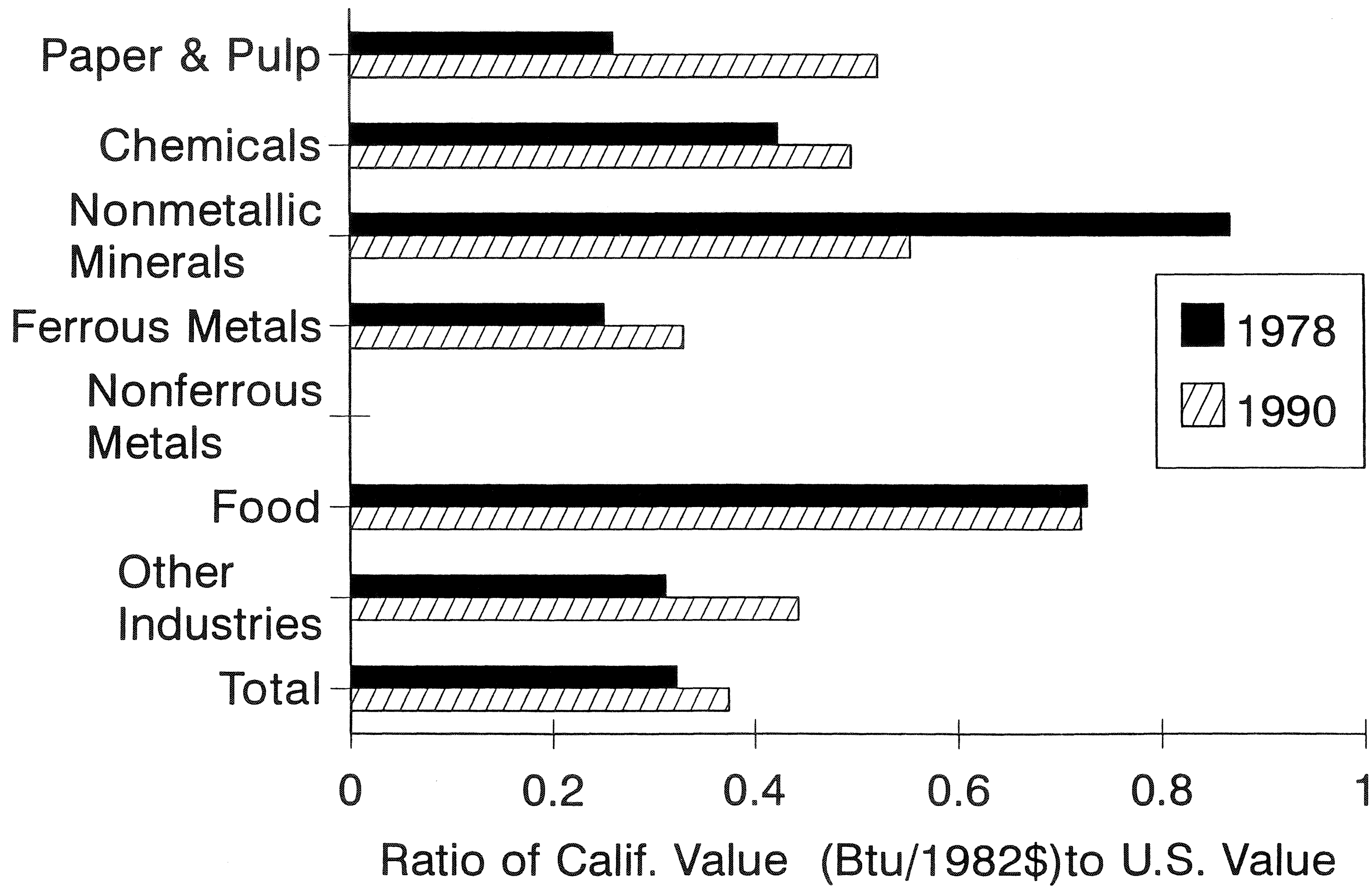
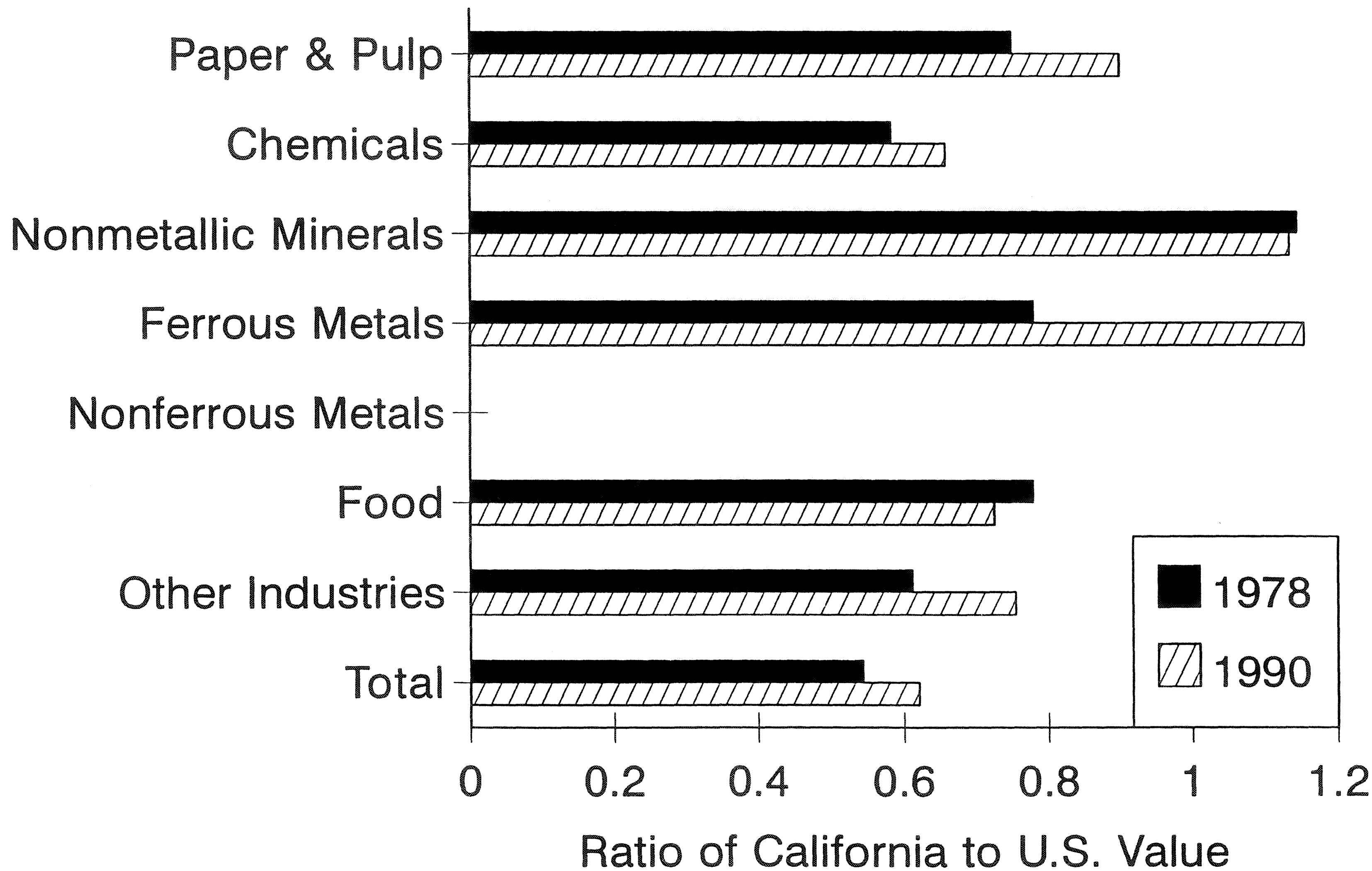


Figure 4.6

# California and U.S. Manufacturing Prinary Energy Use Intensities



## Figure 4.7
# Electricity Intensity in Manufacturing:
## Ratio to U.S. Value



## 5. TRANSPORTATION: TRAVEL, FREIGHT, and OTHER

Transportation consumes approximately 40-45% of California's final energy, depending on whether certain unallocated uses of liquid fuels (bunkers, international aviation, etc) are included in the calculation. This large share (compare with approximately 28% for the nation as a whole) has led many authorities to assume that California's energy use is somehow more transportation dependent than the nation as a whole. Yet our analysis suggests that California is surprisingly close to national average in energy use for travel and freight. Instead, it is the small size of the manufacturing and residential sectors that boost the relative (but not absolute) importance of the transportation sector in California. Figure 5.1 shows transportation energy use by subsector, as we have been able to determine it. A small amount of electricity is included in "rail," but a similar amount of natural gas (for pipelines, typically 20 TBTU) is not shown.

### 5.1. Data Sources

Meaningful analysis of energy use in transportation requires that we split the problem into three parts: energy and activity for travel (in passenger miles, by mode), freight (in ton miles), and uses for which we have no meaningful measure of activity. As we found, it was possible to get measures of activity for most kinds of travel, but difficult to find measures for freight.

We fall back on three main data sources: first, the CEC Energy balances, supplemented by SEDS for electricity and natural gas used for transportation.[13] Second, we used Caltrans' own model data (1980-1992).[14] Caltrans (Herbert Jew, personal communication, 1994) provided data on the average fuel economy of cars in California by vintage, using H.M. Polk automobile survey data for California taken in 1986, 1988, 1990, and 1992 and the EPA ratings of each car and vintage to calculate the sales weighted MPG average. Third, to supplement these data, we obtained information on Amtrak, local transit, and air activity from federal authorities.

The federal data proved to be a boon. Section 15 Data from the U.S. Department of Transportation (published yearly by the Urban Mass Transit Authority) report transit activity and fuel use for each district in California, and give both passenger and vehicle

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[13] Colleen Lim of CEC (personal communication, 1992) provided miscellaneous CEC data for transportation that covered 1978-1990 and agreed with Caltrans and the California Energy Balances.

[14] Luk Lee (personal communication, 1994) kindly provided the Caltrans base year data for each year from 1980 to 1992. Included is fuel use for cars and light trucks, divided into gasoline and diesel, miles travelled by each kind of vehicle (for each fuel), and the number of each kind of vehicle (again, by fuel). These appear in each year's Caltrans Forecast.

miles as well as fuel or electricity consumed. Not all cities report all data each year, but analysis suggests that as much as 90% of all fuel use and 95% of all passenger miles are reported for most years. We were able to obtain the years 1978-1992 and include 1980-81, 1990-91 and several intervening years in our analysis.

Greyhound provided data on intercity bus travel passenger miles, as transmitted by Jack Fulcher, CPUC (personal communication, 1994) and also published by Caltrans. For rail, the 1983 California Transportation Atlas cited Amtrak data for 1980 and 1981 for various trains. Amtrak (P. Westphal, Amtrak Marketing office, Washington, D.C., personal communication, 1994) provided data for total passenger miles on intra-California trains, as well as inter-state trains during the California portions of their travel. Finally, Lou Thompson of the World Bank, formerly with the National Railroad Administration, provided us with some rough estimates of the fuel intensity of Amtrak passenger trains in California in the early 1980s, based on a 1981 report, Rail Passenger Corridors (U.S. Department of Transportation 1981).

Freight data were harder to find. Repeated inquiries with the Interstate Commerce Commission (ICC), the CPUC and the California trucking association produced no estimates of ton miles hauled on California roads. While the Caltrans estimates of vehicle miles driven by truck size were themselves useful (and part of the calculation of fuel used), they do not by themselves indicate "activity" in the sense needed for this study. We also found no data on ton miles of coastal or inland shipping.

For rail freight, the ICC (J. Nash, personal communication) provided us with ton miles hauled wholly within California, as well as ton miles of freight hauled into California. Together with data on tons hauled, we estimated the California portion of interstate freight as 200 miles, multiplied by the number of tons hauled into the state. We estimated that rail freight hauled into California was about equal to that hauled out. First, California is not a large producer of bulk, raw materials, but imports them as well as products made from them. On the other hand, the U.S. as a whole is a net importer of goods, many of which flow into California by sea for further transportation. Lacking any precise balance, we estimated overall that rail haulage out of California is about equal to the haulage into California. Thus our estimate of interstate rail ton miles was derived as tons shipped into California x 200 miles/haul x 2. The California Transportation Atlas gave the value for total ton miles hauled in California from 1978 to 1981, which appears consistent with the values we used for the period 1987 to 1992.

Measuring traffic and energy use for commercial aviation is difficult. Most sources simply report fuel delivered to California airports, and departures or arrivals of planes and passengers. However, the FAA collects data from actual tickets (and from reports from air carriers) on passenger miles and seat miles actually flown by aircraft between all city pairs in the U.S. We obtained many of the original data (on CD rom) from a

U.C. Berkeley Library, supplemented by results from a CPUC study of the same material, which in all cover 1978 to 1992.

We were able to calculate travel within California as follows. We used the FAA reports of passenger activity (air miles, seat miles, stage length, and passenger miles) between the three San Francisco area airports and the five in the Los Angeles Region from 1984 to 1992. Comparison of the numbers of flights with a California Public Utilities Commission study (1989) that covered the years 1981 to 1988 shows that roughly 80% of all flights were in the San Francisco area-Los Angeles corridor. While some of the remaining flights consisted of Sacramento-Los Angeles and Sacramento-San Diego (longer stage length than the San Francisco area-Los Angeles Corridor), most consisted of much shorter flights. Therefore, we assume that the average flight in California is only 90% of the San Francisco area-Los Angeles stage length of approximately 338 miles. From this information we extrapolate passenger miles flown to the entire state for the period 1984-1992. Knowing numbers of departures and passengers for 1981-1984 from one CPUC data set, we extrapolate total travel back to 1981 using a fixed distance travelled and the number of passengers. From another CPUC data set, we extrapolate back to 1971. This gives us total air travel within California.

CEC gives data for transportation fuels. We use Caltrans data for automobiles, light trucks, and other trucks. Counting passenger rail travel at 60 passenger miles/gallon (L. Thompson of the World Bank, formerly with the National Railroad Administration, personal communication, 1994), we estimated the diesel fuel required for passenger rail and subtracted this from the rail diesel given from California sources (approximately 35 TBTU in 1991) to get energy use for rail freight. We allocated all electricity (from SEDS) to rail, both heavy rail (BART) as well as light rail (many city tram systems). Similarly, CEC sources give data for bus fuel use, which we did not attempt to allocate between intercity busses and city busses, which we suspect is the larger of the two. However, for a few years we were able to estimate energy use and travel for city busses.

Airline fuel, mostly jet kerosene, represents about 16% of the energy in liquid fuels consumed for transportation in California in 1991.[15] For the present study, we use the

[15] Using a variety of FAA data, we can calculate air miles, seat miles, and passenger miles for flights between any two city pairs anywhere in the U.S. Since these can be divided up by airplane and airline, and since the fuel consumption for each airplane type is known, we could in principle estimate total fuel used for flights within California airports, for flights from California to other U.S. cities, and, with some difficulty, to important foreign destinations in Asia, Europe, and even Latin America. This would allow us to divide up the airline fuel delivered to California airports into these three markets. Making assumptions about how much of this traffic represents travel of Californians, or travel of tourists to California, we could estimate the fuel consumption of airlines related to California's economy and the part that represents transit traffic.

average intensity of air travel in the U.S. for each year, multiplied by 1.25 to account for the shorter stage length of flights within California, 335 miles vs around twice as much for the U.S. as a whole. This yields a first order approximation of energy intensity of travel within California, an approximation suggested by United Airlines.[16] The result, approximately 25 TBTU in 1990 for intra-California air travel, is less than 6% of the total sale of jet fuel in California in 1990.

About 400 TBTU of distillate fuels were consumed for transportation in California in 1991. Since road diesel accounts for 250 TBTU and rail accounts for slightly over 30 TBU, this implies about 130 TBTU for inland shipping and other uses. Unfortunately, no further information on this remaining consumption was available. Similarly, about 390 TBTU of residual fuel oil (for large ships?) was consumed according to CEC data. We have no idea how much of this consumption went to bunkering of international shipping and how much went for "domestic shipping" (particularly oil tankers), whether within California or to other U.S. ports.

Our analysis thus deals with energy use for rail, local transit, cars/personal light trucks, and other trucks. Together these uses account for slightly under 70% of the fuel used in California. However, if we assume that well over 80% of the aviation fuel and at least the same share of ship fuel is used for vehicles leaving the state, then we have a residual of only 200 TBTU out of a total of approximately 2,250 TBTU in 1991.

## 5.2. Travel

Automobiles and personal light trucks dominate activity and energy use. We include the energy use for light trucks (Caltrans Type One Trucks, up to 10,000 lbs) in this estimate, adopting U.S. figures for the share of light trucks effectively used as automobiles (about 45% in 1970, rising to 65% in 1992), which we refer to as "personal light trucks."[17] To calculate travel for California we multiply Caltrans' estimates of vehicle miles traveled (VMT) for automobiles and personal light trucks times the same average load factors for the U.S. from values measured in 1969, 1977, 1983, and 1990 using the *Nationwide Personal Transportation Survey* (NPTS).[18] The results can be compared to travel on rail and bus for years for which data are available, and show, not surprisingly,

[16] D. Sturz, United Operations, personal communication.

[17] See various editions of the Oak Ridge National Laboratory's Transportation Energy Data Book or the Eno Foundation's Transportation in America.

[18] We adjusted the Caltrans figure for VMT in 1980 downward. Their figures imply a drop in travel of nearly 25% between 1980 and 1981, as compared to a 3% drop nationwide. The original Caltrans figure implied a very high MPG for the California stock when we adjusted VMT downward to give a change with 1981.

that travel by automobile travel overwhelms that by bus or rail. For air travel within California, the method described above yields about 150 passenger miles/capita in the late 1990s, about 10% of the national average. Figure 5.2 shows the results in per capita terms.

If we examine automobiles and personal light trucks more closely, we find interesting results. There are only 0.88 cars/personal light trucks per licensed driver, vs over 1 for the nation as a whole. Slightly under 2/3 of the population has a driver's license. This figure rose slowly from 1970 through the late 1980s, then remained stagnant and fell, perhaps as new immigrants came to the state who did not drive. Whatever the causes, the picture that we see is of a state with average or even less-than-average motorization rates.

Using the Caltrans data noted above, we find that on-road car/light truck MPG rose from about 14 in 1980 to 21.5 in 1992. VMT/vehicle, which was depressed in 1980 at around 10,000 miles, rose with a national trend to nearly 12,000 miles by 1992, but given the slightly lower number of cars and light trucks in California, the per capita value for VMT, 7059, is low by national standards. Combining these trends yields energy use for personal vehicles in 1991 only 10% higher than in 1978, consistent with national trends.

Rail and bus travel were included for a number of years in Figure 5.1. Energy use for these modes is very small, but it is notable that energy use per passenger mile for city busses is roughly equal to that for cars, according to available data from the U.S. Dept. of Transportation Section 15 reports (DOT various years). Travel by intercity rail is very low, but travel by local rail may be high by national standards, given the importance of BART, CALTRAIN, and the many light rail systems throughout California. Still, travel on rail and bus is small compared to travel within California by air.

We have estimated the weighted average fuel economy of new cars sold in California from Caltrans data provided by Herbert Jew (personal communication). If we assume that a survey taken in year N contains a sample of cars from years N-1 and N-2 that represent cars bought by Californians in those years, we can use the sales-weighted average fuel economies Mr. Jew calculated for those vintages and years. Using years before N-2 risks arriving at a stock that has been shrunk by attrition and moves out of the state and increased by moves into the state. (Comparison of numbers of cars in each vintage over time confirms that attrition dominates.[19]) When the results are tabulated, it appears that since 1980, Californians have bought a mix of cars with a slightly lower

[19] Taking the cars in Year N is not quite representative, because the survey itself is taken in early July, just before the final cars for the model year are sold.

fuel intensity than Americans as a whole. These results are shown in Fig. 5.3, along with on-road estimates for cars.

## 5.3. Freight

Caltrans' model estimates total truck activity in VMT for four truck types. After removing the trucks considered "personal light trucks," we allocate the remaining activity to freight haulage. However, there is no measure of ton miles hauled for any part of this stock. And since the fuel intensity of the stock is highly dependent upon the mix of trucks by size, we cannot report a fair figure for energy productivity of trucks. Moreover, some of the truck activity represents out-of-state trucks coming to California and turning around. Thus it is impossible to separate intrastate activity from interstate activity. Nevertheless, the total consumption of fuels by trucks is nearly 600 TBTU, or 45% of that of automobiles. It is unfortunate that there are no measures of activity to complement this significant consumption of energy.

Rail freight activity is dominated by transit freight (i.e., freight into or out of California), according to our estimates described above. Even allowing for uncertainties in the proper allocation between passenger and freight, however, rail freight consumes only 30 TBTU of fuel, far less than trucks or the reported quantities of fuel consumed by shipping. Hence rail freight represents a relatively unimportant part of California's energy consumption.

DOE data (SEDS) indicate about 20 TBTU were consumed as natural gas, presumably in natural gas pipelines. This is far less than California's share of the national total, over 700 TBTU. By contrast, the nearly 500 TBTU indicated for jet fuel sales in California (after removing the small amount for intra-California travel) represents three times the per capita "consumption" than in the U.S. as a whole.

## 5.4. Comparison with National Trends

The foregoing permits a limited analysis of California trends compared with the U.S. as a whole. We can make some important global comparisons from these data.[20]

First, California's total energy use per capita for transportation is higher than that for the nation as a whole because of the importance of her airports and sea ports. Per capita fuel use for cars is actually lower in California than in the U.S. as a whole, while that for trucks about the same. Rail energy use is far below that for the rest of the nation. But, as we have seen, at least 90% of the energy associated with air travel, well over half for

[20] Throughout this section the source of US data is the Oak Ridge Data Book, with modifications as discussed herein.

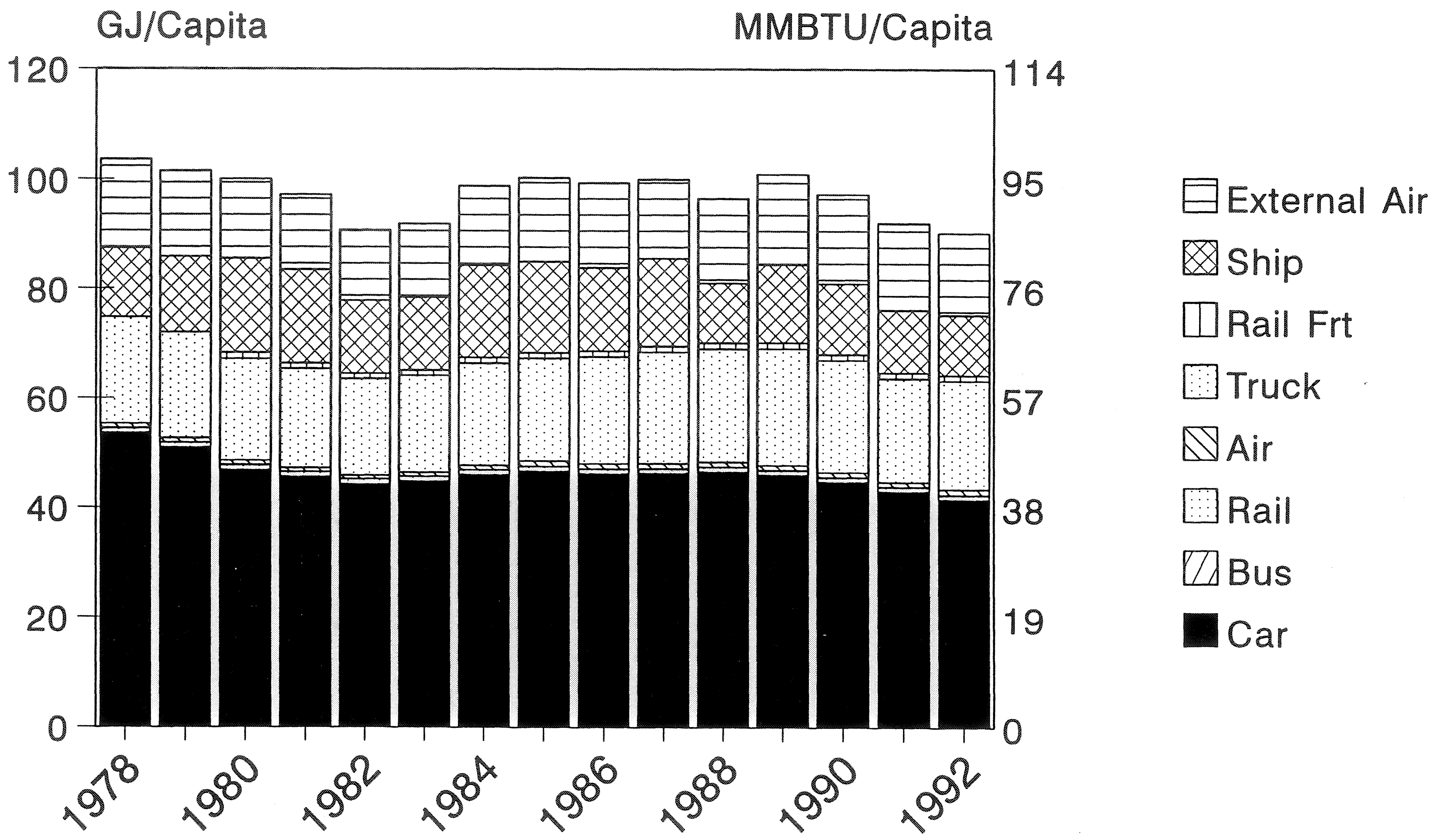
rail freight, most of that for water-going shipping, and probably a significant share of that for trucking is related to interstate commerce. Thus, most of the difference between national and California's transportation energy use is due to significant interstate travel and freight.

Figure 5.3 shows basic comparisons of car ownership and other parameters of travel. California appears close to the U.S. average. In 1990 Californians had somewhat fewer cars/capita than Americans and drove them slightly less. For total travel, Californians have slightly lower automobile travel/capita than the rest of the nation, which follows from the data in Figure 5.3 and our assumption that the load factor in cars in California is the same as the national average. In California, intercity bus and intercity rail travel are well below the nation, transit bus ridership slightly below, and transit rail ridership slightly higher than the national average. Air travel within California is below that of the national average (per capita), but the total air travel of Californians is unknown.

Figure 5.4 shows fuel intensity in more detail. We see the MPG of the fleet of cars (and light trucks) in California and the U.S., and compare our estimate of new car MPG in California with that published for the U.S. (Davis 1994). It appears that Californians have bought slightly less fuel-intensive cars than other Americans, leading to a slightly higher MPG for California cars than for the nation as a whole. Uncertainties in both national and California figures rob this small difference of any significance. Transit bus energy intensity appears to be about the same as for the nation as a whole. For air travel, we assumed that the shorter distances in California boost intensity 25%; in fact the load factors in California lie around 60-65%, near the national average, so we believe this 25% boost to account for the shorter stage length in California is justified.

The analysis of the transportation sector leads to a surprise: More energy per capita is consumed by the transportation sector in California than in the nation as a whole, but this difference is caused in large part by California's important geographical location, leading to important fuel used in interstate and international traffic. In fact, we estimate that 90% of the jet fuel, more than 80% of the rail fuel, most of the marine fuel, and at least 1/4 of the trucking fuel appears to be tied to interstate commerce, boosting the per capita energy use of the Californian economic for transportation by as much as 50% over a likely level for internal transportation. As for the automobile itself, Californians do not have a "love affair" with the automobile any more so than Americans on average; in fact, in the early 1990s, Californians appeared to be less dependent upon automobiles, and used less energy per capita for automobiles (and light trucks) than did Americans in other states. Some of this differences are accounted for by the frequency of flying in the Los Angeles/San Francisco area corridor. The congestion and smog problem is probably the main reason that the image of automobile use in California seems to have led to a misunderstanding of the role of transportation.

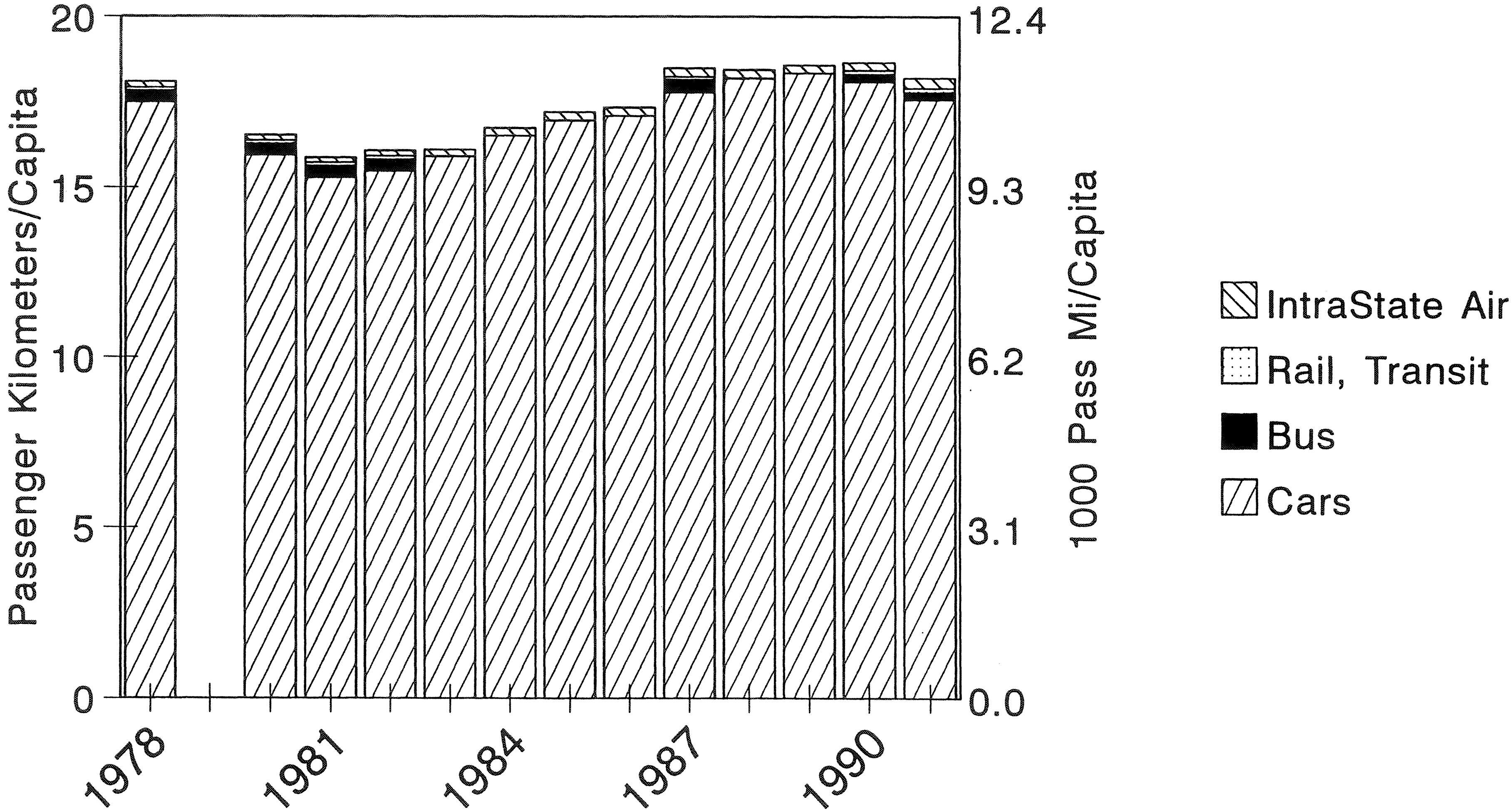
# Figure 5.1
# Energy Use for Transportation In California




Source: LBL Calculations from CEC, Caltrans, Federal Sources

Figure 5.2

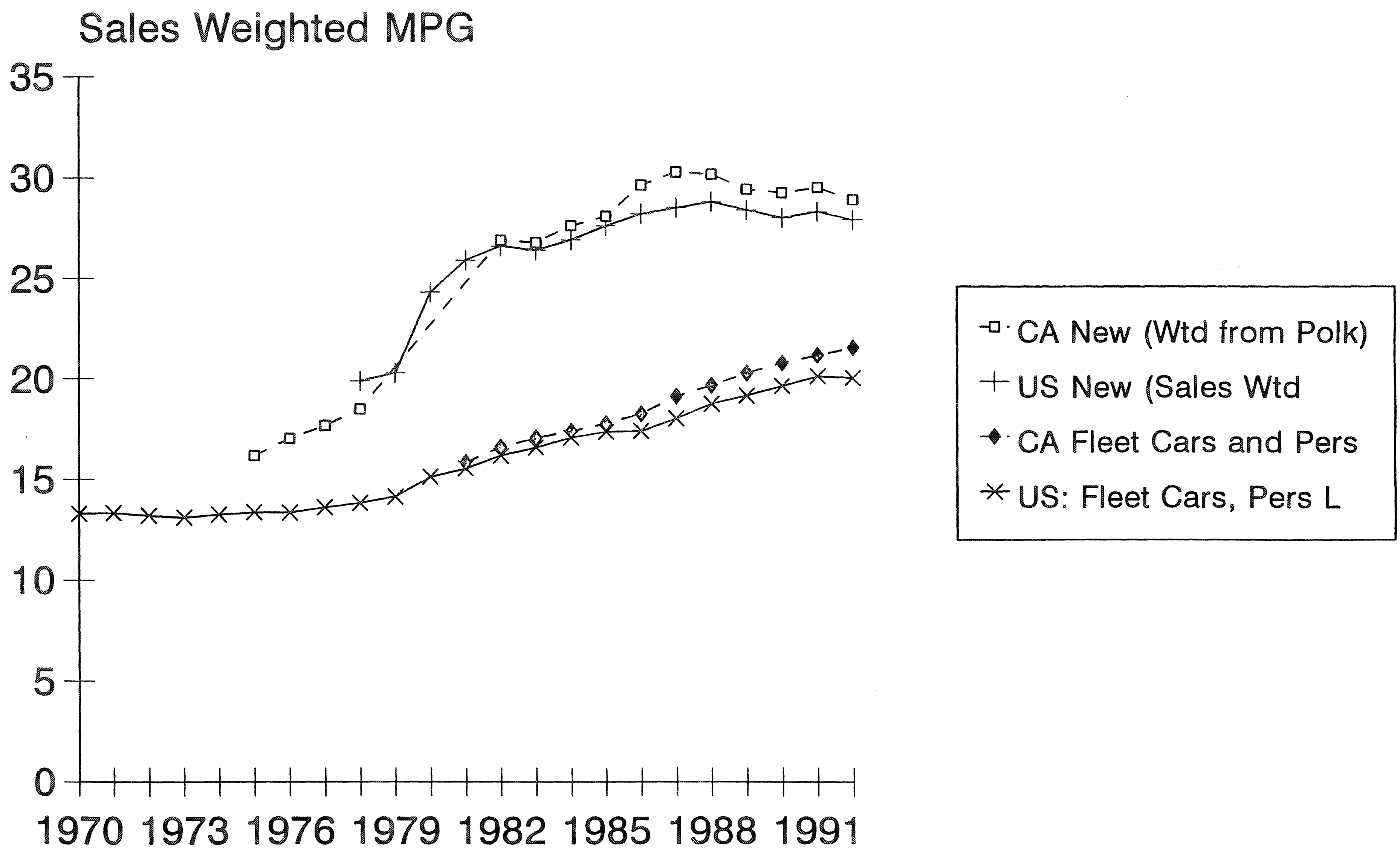
# Per Capita Travel by Californians



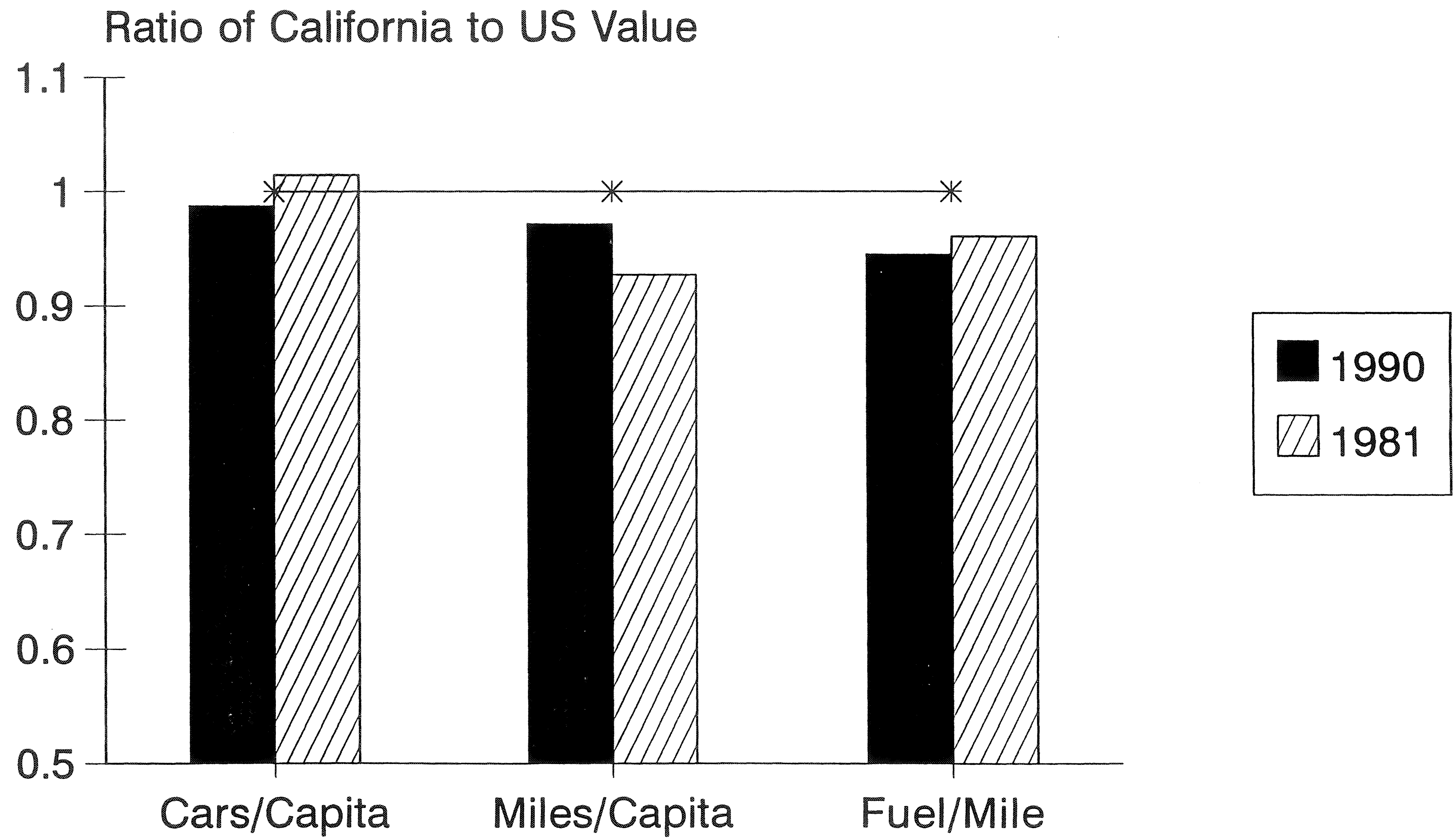

Source: LBL Data Base
Total Primary Includes miscellaneous final demand and all production losses.
Gas and oil Pipelines included in "total" primary.

## Figure 5.3

# Average Fuel Economy of Passenger Cars



## Figure 5.4
# California Automobile Use
## Comparison of Ownership, Driving, and Fuel Intensity



# 6. SUMMARY OF TRENDS IN THE STRUCTURE AND INTENSITY OF ENERGY USE IN CALIFORNIA

The ratio of final energy use to GSP in California declined by 28% between 1978 and 1990. How much of this decline was caused by lower energy intensities and/or higher energy productivity, how much by structural change? Data do not permit us to answer these questions for all sectors and uses, but we account below for about 80% of energy use.

## 6.1. Structural Trends in California's Economy

Figure 6.1 summarizes the key activity and structural indicators in California, each indexed to 1978 values = 100. Manufacturing and services GSP grew at nearly the rate of overall GSP. The share of manufacturing in California's GSP fell only slightly between 1978 and 1990, but the share of heavy industry within manufacturing fell significantly, from 13% to only 9% of GSP in manufacturing. Conversely, the share of services grew slightly. The overall housing stock and area heated grew less rapidly than overall GSP, as did total car travel, although both increased. There appears to be a small increase in share of travel using transit, if we start in 1973 before the BART system and other large-scale networks were established. Overall, these factors reduced the ratio of energy use to GSP in California. The increase in electricity-using equipment in households and the service sector increased energy use. All together, it appears that these trends reduced per capita energy use in California (all else equal), and, equally important, reduced California's ratio of energy use to GSP. We estimate that roughly one-third of the decline in that ratio arose because of these structural changes alone.

## 6.2. Intensity Trends from the Late 1970s to 1990

Certain key energy intensities in California fell significantly. These are shown in Figure 6.2. Intensities of two-digit branches of manufacturing, for example, fell by 36%, primary energy intensities by 30%. Space heating intensity (measured in useful energy) fell by 25%. Household appliance intensities (holding the 1978 mix of appliances constant) fell by 22%. Fuel use/sq. ft. in the service sector fell by 7%, and fell 21% relative to value added in this sector. The intensity of electricity use increased slightly, but we believe that this trend is composed of a significant increase in electrification (lighting, ventilation and cooling, computers) almost offset by a large decrease in the intensities some of these use.

Transportation showed falling energy intensities. Fuel use per mile driven in the car fleet dropped 21% between 1980 and 1990, and fuel use per passenger mile fell 12% in this period. Fuel use per vehicle mile of truck declined roughly 20% for light trucks and 10% for other trucks.

From these indicators we find that California's energy intensities fell about 20% on average between 1978 and 1990. This means that roughly two-thirds of the 28% decline in the ratio of final energy use to GSP California experienced between 1978 and 1990 arose because individual energy intensities themselves declined.

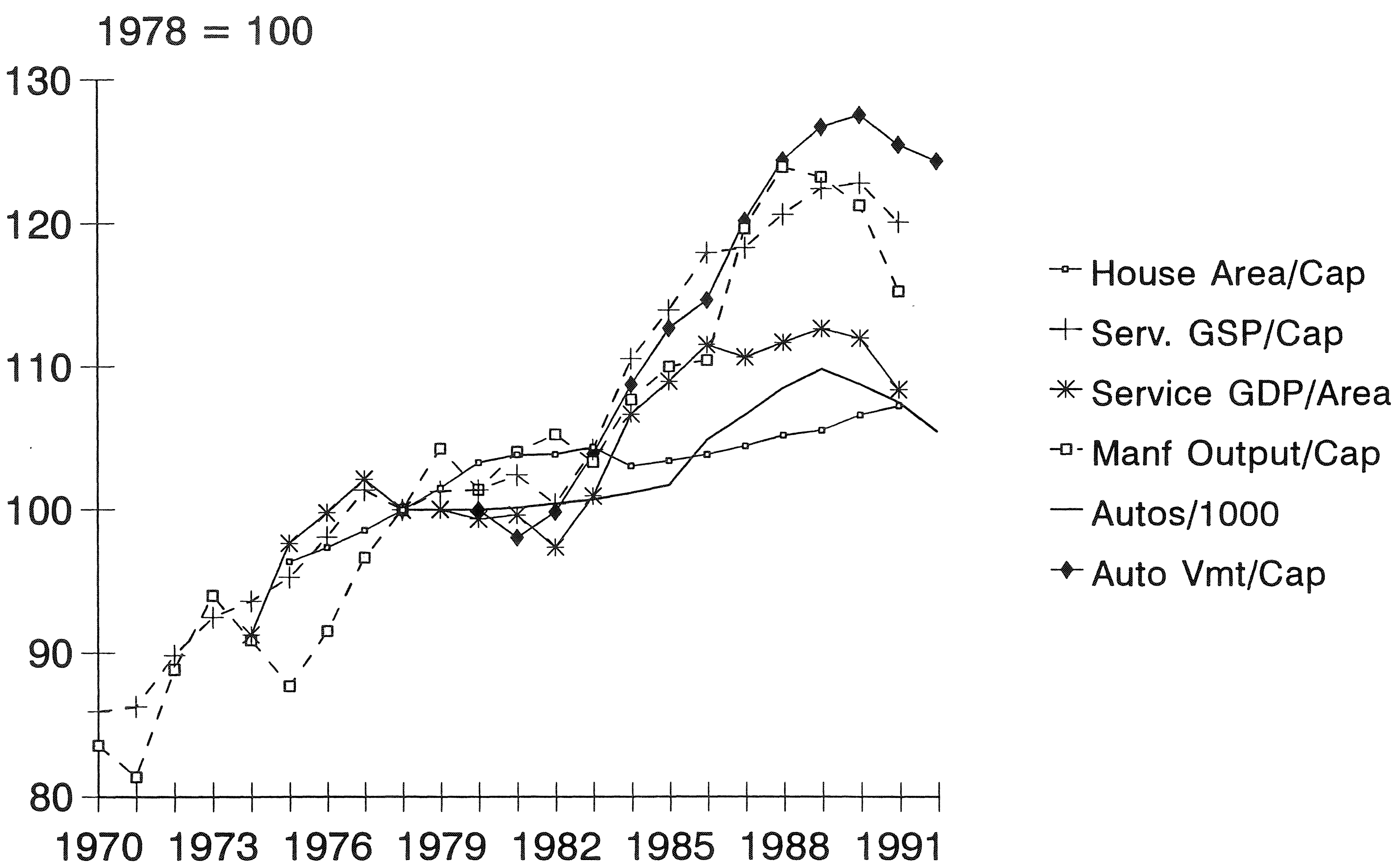
## 6.3. Energy Prices in California

Figure 6.3 shows real energy prices in California between 1970 and 1991, from DOE State Energy Price Data. In 1975, California energy prices were in general 25% higher than they had been in 1970, even after correction for inflation. They peaked in the early 1980s, and fell back slowly thereafter, falling even more rapidly after the price crash in World Oil Prices in 1986. The one major exception is residential electricity prices, which increased after 1986 although the prices for road fuels moved up in 1990 and 1991 during the Gulf hostilities.

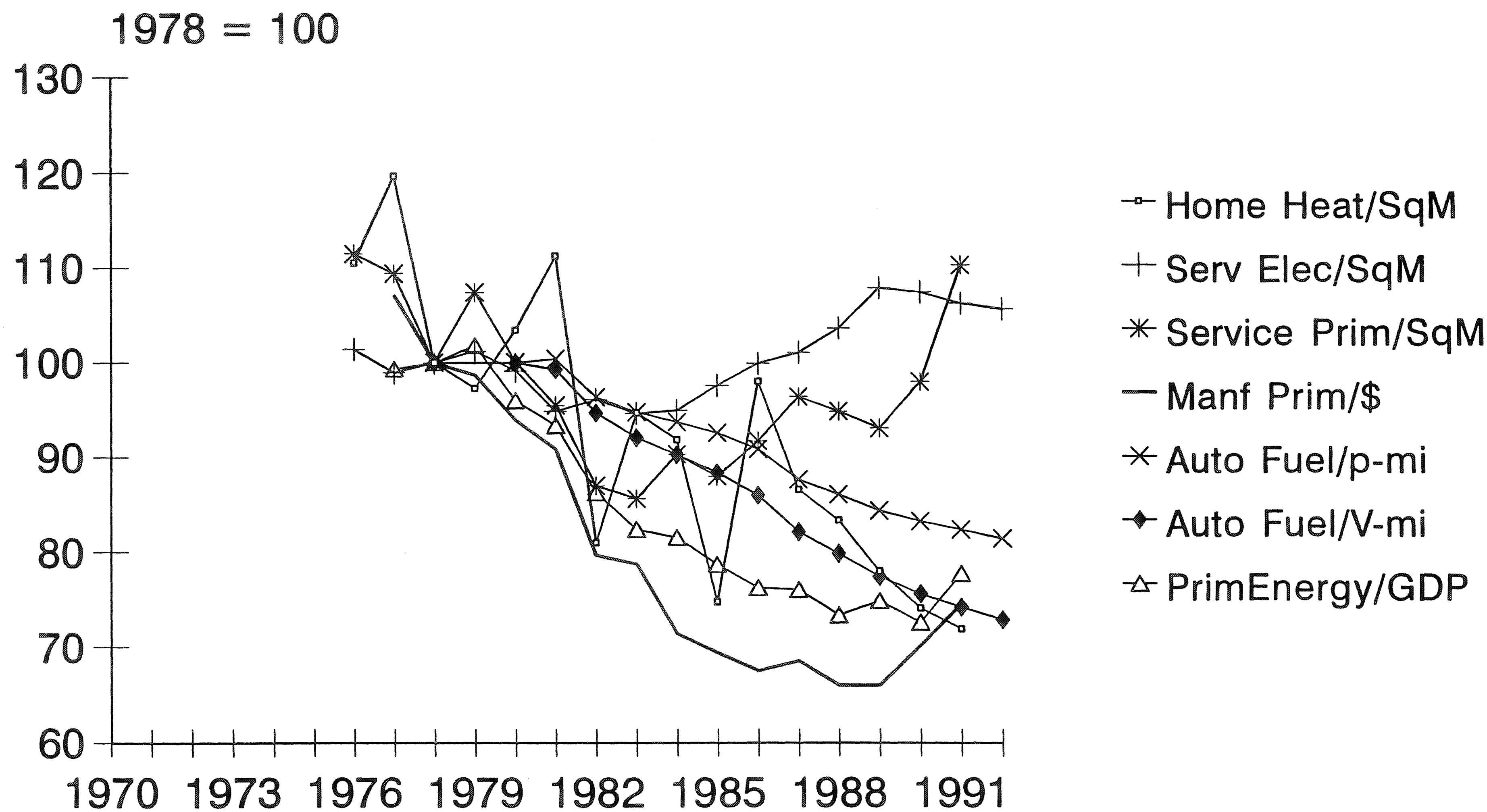
Figure 6.4 shows how California's prices compared with those for the U.S. as a whole, using the same DOE data source. In 1970 most prices in California were lower than in the U.S. as a whole, some considerably lower. By 1980 this was true only for residential gas and commercial electricity. By 1991, only gasoline was cheaper in California. Thus the pressure of higher energy prices was successively greater in California than in the U.S., or, rather, the decline of prices after 1986 was greater in the U.S. as a whole than in California.

These differences are striking. How or why they arose is beyond the scope of this report. At the same time, it should be noted that the structure of output of California's industry has always been less energy intensive than that of the nation's, and that California households and buildings require less heat than those of the nation on average. In other words, higher energy prices do not mean Californian's spend more for energy than other Americans, because Californians use so much less energy. When the price of each fuel is weighted by its actual consumption, Californians paid 5% higher average prices than Americans in 1970, 4% more in 1975, as much as 12% more in 1980, 8% more in the late 1980s, and 10% more in 1991. Since California used only 70% as much energy per capita as the U.S., this rough comparison supports the finding that California is burdened less by energy costs than the nation as a whole.

# Figure 6.1
# California's Economy: Key Structural Indicators



# Figure 6.2
# California's Economy: Key Energy Intensities




(Autos 1980 = 100)

## Figure 6.3
# Real Energy Prices in California (Relative Values)

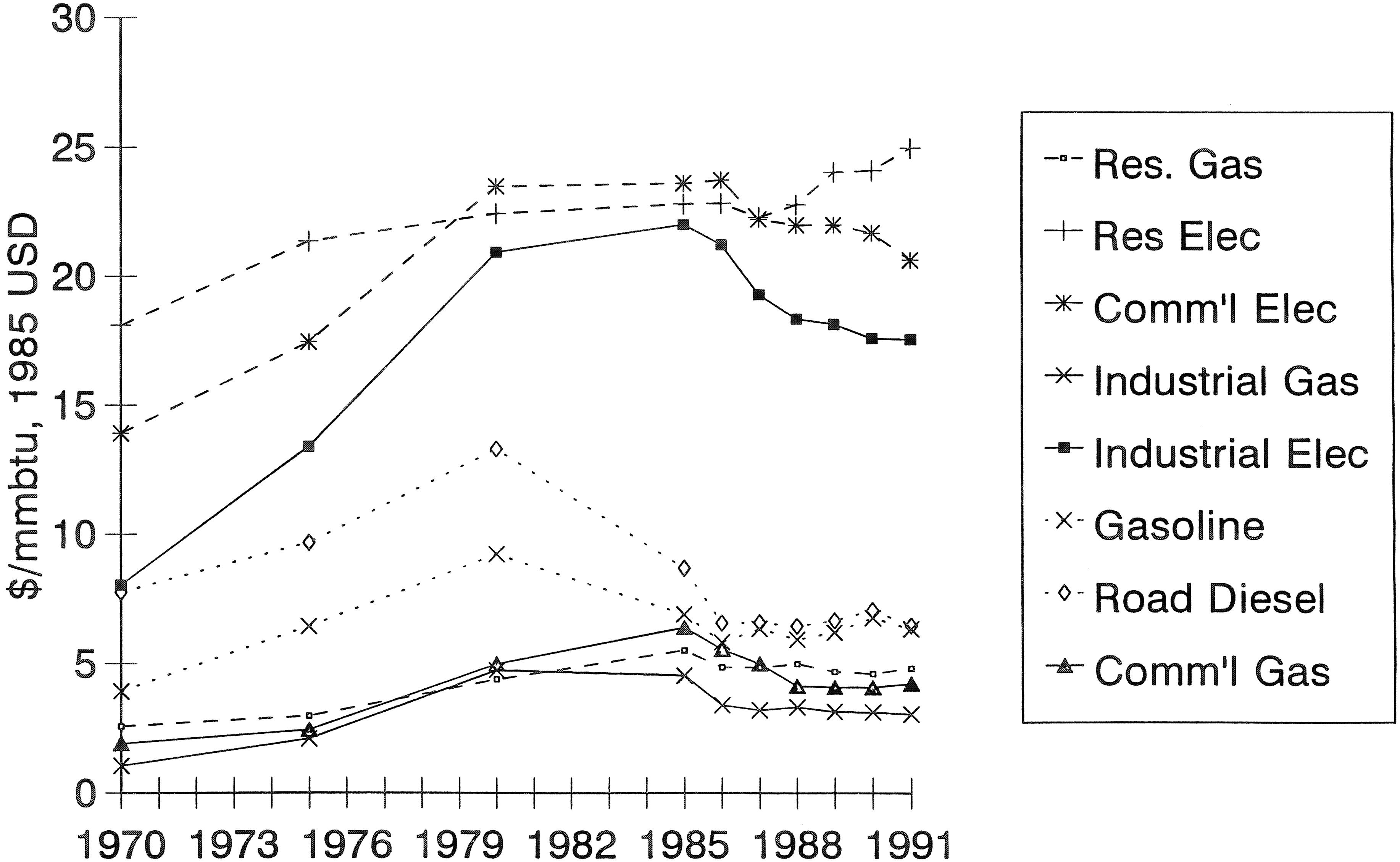
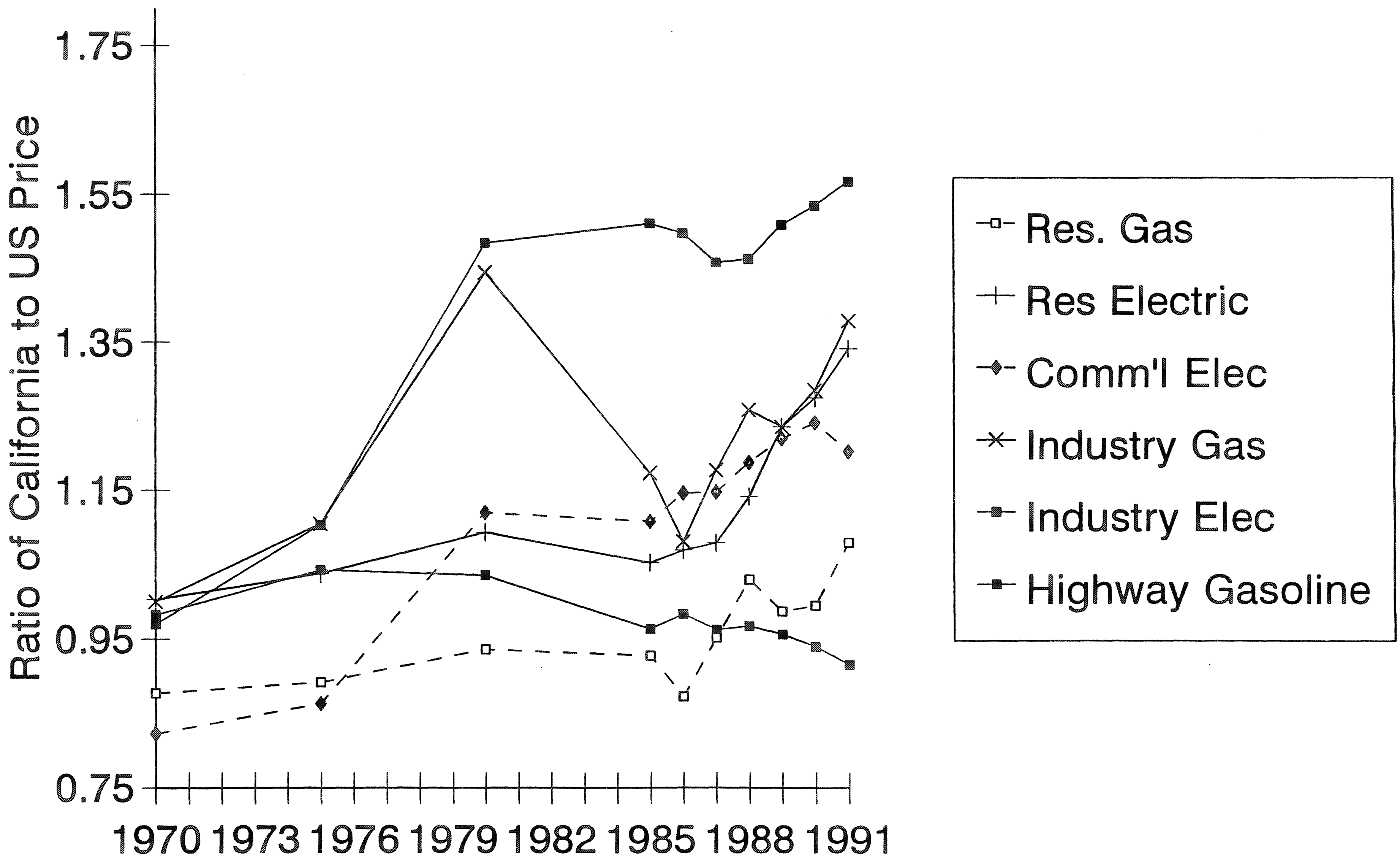


Figure 6.4

# Energy Prices in California & U.S. (Relative Values)



# 7. COMPARISON WITH THE UNITED STATES

After we compared certain energy aggregates from California and the U.S. (Figure 1.1), we argued that these aggregates make poor measures of energy productivity or efficiency. Instead, we should distinguish between differences in structure and differences in intensity, since it is the latter that are related to energy productivity. However, the former may also account for a significant part of the overall difference in energy use between two regions or countries (Schipper, Meyers, et al. 1992). Because of data problems, our time-series comparison begins in 1978.

Figure 7.1 shows per capita energy use in California and the U.S. in 1990 in two parts. The two columns to the left show those parts of energy use that are more or less directly comparable: households, services, manufacturing, land travel, and trucking. The right-hand columns show energy uses not readily comparable, such as fuel for airlines, rail and sea freight, and "other industry," the ill-defined catch-all for other consumption outside of electric utilities. The higher consumption of jet fuel and fuel for sea-going freight (bunkers) arises because of California's geographical position. In spite of these data problems, many important comparisons are possible among the uses in the left group of columns. With these caveats in mind, we show per capita sectoral energy use in both regions in Figure 7.2. We focus on the 1990 differences and the changes between 1978 and 1990, because data for these two years are reliable.[21]

## 7.1. Structural Differences

In each sectoral chapter we compared key structural indicators describing California and the U.S. Figure 7.3 shows per capita GDP for both entities in 1978 and 1990, split into four subsectors. Other more disaggregated differences were outlined in the discussion of each sector.

First, the differences between the structure of the two economies (ignoring that California itself is roughly 12% of the U.S. economy) are important:

- The manufacturing sector is less important in California than in the U.S. and produces proportionately less energy-intensive output;

- California has a far milder heating climate than the U.S. as a whole (about 36% as many HDDs);

[21] Unfortunately the Caltrans analysis of road transportation begins in 1980. CEC estimates of road transportation energy use (Colleen Lim, personal communication, 1992) agree closely with the figures used by Caltrans, but we have no corresponding measures of fuel intensity or distances driven (VMT) for vehicles for 1978. Hence our comparisons of automobiles span the 1980-1990 period.

- California's homes are very slightly smaller than the national average, in part because California has a smaller share of single-family dwellings than the nation's housing stock as a whole;

- A far smaller share of households in California use electricity for water- or space-heat than in the nation as a whole;

- Household size in California is now larger than in the nation as a whole, which reduces per capita energy use in households as more uses are "shared" (Schipper et al. 1989);

- Although California has higher per-capita service-sector GDP than the U.S., it appears to have less per-capita floor area in the service sector; and

- Although California has a higher share of output in agriculture, this sector tends not to be energy intensive relative to manufacturing, which is another factor lowering California's energy use.

One factor appears to be "neutral" in terms of its influence on differences between energy use in California and the U.S. as a whole:

- Californians have roughly the same automobile ownership and use as Americans as a whole (surprisingly).

Some factors raise California's energy use relative to the nation:

- California has somewhat more CDDs than the nation as a whole, raising energy use in households and possibly services (all else equal), although the share of homes with A/C is somewhat lower than in the nation as a whole;

- Lacking high population densities or natural rail corridors (and few centers of raw materials production), California appears to be less dependent on rail and more on road traffic than much of the rest of the nation;

- California has two important air hubs, which leads to considerably more intra-state air traffic than other states, raising energy use; and

- Like Washington, New York, Illinois, and Florida, California has important sea and air termini that attract transit passenger and freight traffic, which raises apparent energy consumption within the state.

We estimate that these factors on the whole reduce California's energy use by 20-30% relative to its GSP, compared with the nation as a whole. In other words, were the nation to have these structural features, overall energy use relative to GSP would be 20-30% lower than it actually is. Thus the structure of California's economy is significantly less energy intensive than that of the nation as a whole. Put another way, California would use roughly 25% more energy if it had the nation's manufacturing structure, climate, and housing structure.

### 7.1.2. Intensity Differences

Energy intensities in California tend to be lower than in the nation as a whole. The most dramatic differences are those in manufacturing. Differences among transport modes are not statistically significant. The most important exceptions are space and water heating and the use of electricity in the service sector. Overall, differences in energy intensities reduce California's 1990 energy use by about 10% relative to the nation as a whole. (Recall that we can only measure the intensity of 80% of the energy use in the comparison, but the remaining consumption, principally freight transportation, is not likely to contribute enough different to change this result.)

### 7.1.3. Summary of California-U.S. Differences.

Figure 7.4 shows manufacturing energy use in California in 1990, as well as values that would have been obtained if California had the U.S. per capita output mix or U.S. intensities. Substituting either factor raises California's energy use by about 1/3, indicating the equal importance of **both** components in accounting for differences in energy use in manufacturing. Figure 7.5 summarizes this finding for the household heating and appliances and service sector electricity and total energy. In both examples, we show how much energy the U.S. requires for an important end-use, and how much would have been used had the U.S. had the same structural parameters for that end-use as California.[22] California would use more energy for space heating because of the colder U.S. climate, but somewhat less if California had the lower space heating intensity of the U.S. California would use some more electricity for appliances with the U.S. structure (with more appliances per capita), but much more due to the higher U.S. intensities. Conversely, the U.S. would use less energy with California's manufacturing mix or climate, less energy with California's manufacturing energy intensities, but more with California's space heating intensities.

[22] We have chosen to use the U.S. as a base because U.S. energy use data are considerably more accurate than California energy use data, while structural data for both regions are equally as reliable.

Figure 7.6 combines these results to portray California's electricity use, delivered energy, and primary energy in the following ways: (1) actual in 1990; (2) with the U.S. structure of 1990 for the sectors portrayed in Figures 7.4 and 7.5; and (3) with the intensities of those sectors. With the U.S. structure, electricity use in California remains about the same, but delivered and primary energy are each about 1/3 higher. With U.S. intensities, California energy uses are about 25% higher than actual. This demonstrates that for the sectors we can fully disaggregate, the structural differences between California and the U.S. are responsible for a greater part of the California/U.S. energy difference than are the intensity differences. Only for the service sector (using GDP) is California's economy more energy intensive than the U.S. as a whole, and then only because California has higher service sector output than the nation. In the transportation sector (not shown), the differences between California and the U.S. are almost wholly related to interstate traffic, California's important transit freight and air travel traffic boosting energy use in California for transportation by nearly 30%. Among sectors of transportation directly comparable, the main difference seems to be lower reliance on rail for freight.

In all, differences in the structure of energy use and differences in energy intensities reduce California's energy use relative to that of the nation as a whole. We find that between 1/4 and 1/3 of the difference between the American and the California ratio of energy to GNP is a result of lower energy intensities in California. The rest of the difference arises because California's milder climate, slightly smaller homes, and manufacturing base are less energy intensive than for the nation as a whole.

Why does California have a less energy intensive structure than the U.S. as a whole? The mild climate in California is one reason it has become a popular state. Lack of raw materials (ores, coal, large reserves of oil or gas, or a large endowment of hydro power) is one reason why California does not have a base of heavy industry. Another reason why California does not have a heavy manufacturing base is that much of the U.S. base was developed before World War One in the Central and Eastern U.S., before California figured as an important, large state.

## 7.2. Time Trends in California and the U.S. Contrasted

The ratio of final energy use to GSP in California has declined by 18% between 1978 and 1991, while that for the nation as a whole declined 17%. In primary terms, that ratio declined 26% for California but 22% for the nation as a whole. Since the main difference between these two measures arises because the "primary" measure includes the losses incurred in producing electricity, a rising share of electricity in an economy reduces the decline in primary energy - GDP relative to the decline measured using final energy. California had a smaller share of electricity than the U.S. as a whole in 1978, and that gap grew. This explains in part why California's primary energy/GDP ratio fell more than the same quantity for the U.S. as a whole.

### 7.2.1. Structural Differences over Time

Structural changes in both the U.S. and California economies had an important impact on energy use. These tended to reduce energy consumption in both regions, but at a somewhat higher rate in California. The share of energy intensive manufacturing in California declined relatively more than in the U.S. Although the importance of manufacturing total energy use was already in 1973 considerably less in California than in the U.S., this particular difference in trends **increased** the gap between California and the U.S.

In the household sector, home area in California grew slightly faster than in the U.S., catching up to 93% of the U.S. area. But because of the changes in household size, per capita home area actually grew more in the U.S. than in California. Since house area per capita is an important driver of space heating, this change reduced slightly the importance of space heating in California relative to that in the U.S. Interestingly, appliance ownership grew slightly more in the U.S. than in California. That is, if we hold appliance energy intensities constant at their 1978 values and let the saturations in each region increase, the resulting growth index we obtain for the U.S. is 115%, vs only 110% for California. Since California household size shrunk less than for the U.S. as a whole, and actually increased after the mid-1980s, this means that per capita appliance ownership in California grew about 15% less than it did in the U.S. Overall these two factors (house area/capita) and (appliances/capita) led to less growth in California than in the U.S. as a whole.

Service sector output and area grew faster in California than the U.S. But the gap between output and area grew faster in California, that is, output over area grew faster in California than in the nation as a whole. In all, these differences tended to increase energy for services slightly faster in California than in the U.S. (because of differences in overall growth rates). But a consequence of the growth of California's service sector was a consequent more rapid (albeit small) decline in the role of manufacturing in California vs in the U.S.

Total travel (as defined in Section 5) appears to have increased slightly less in California than in the U.S. Total freight (in ton miles) in California is indeterminate. From the available data, however, we conclude that the important structural changes in manufacturing reduced energy use in California more than in the U.S. This effect was reinforced by strong growth in the service sector in California. As a result, structural change reduced energy use in California slightly more than it did in California.

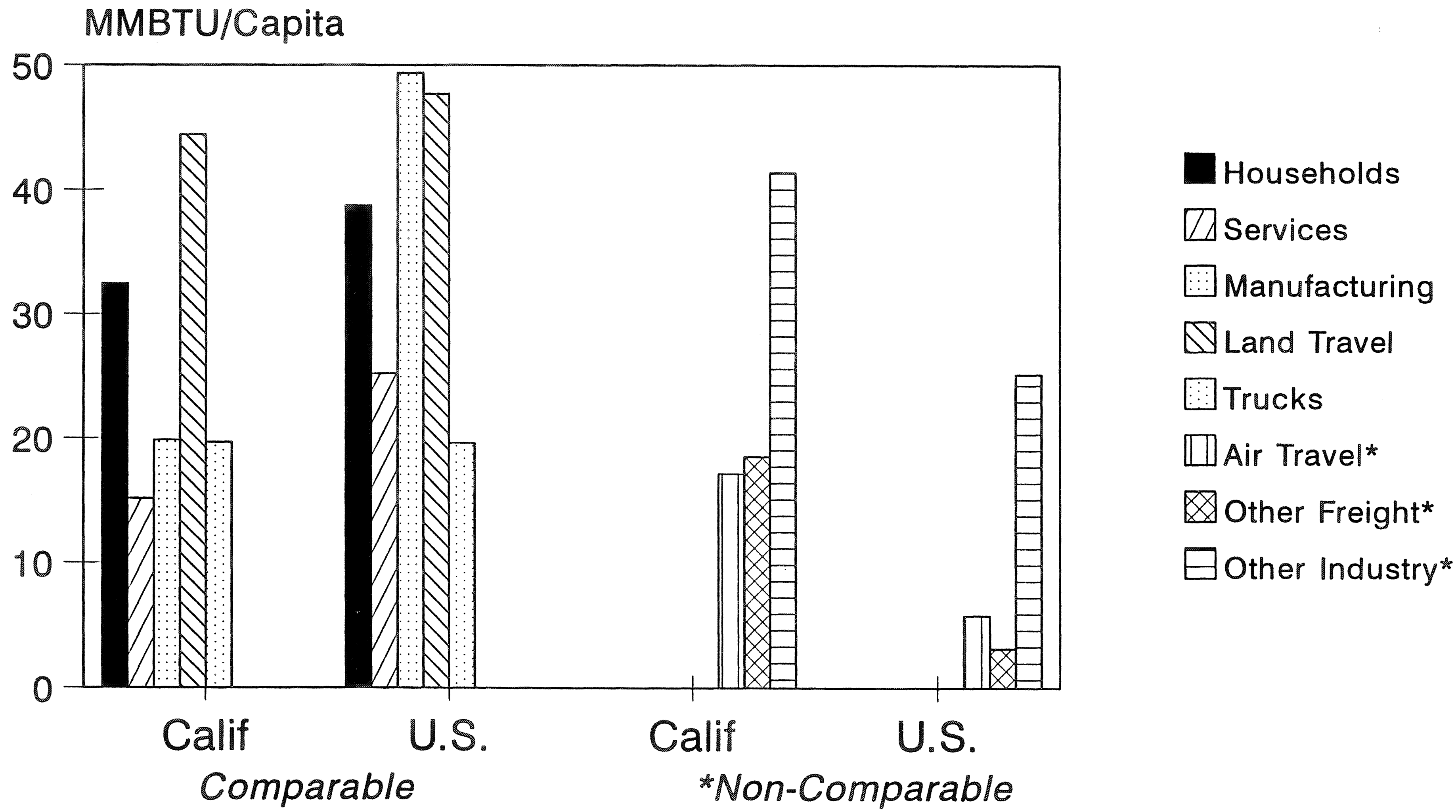
### 7.2.2. Intensity Differences Over Time

Energy intensities in California fell more than they did in the U.S. as a whole. This is particularly true for manufacturing, but intensities for space heating, appliances (22% decline in appliance intensity in California vs only 9% for the U.S. as a whole) and automobiles also fell more rapidly in California than in the U.S., although the uncertainties in these estimates are significant relative to the differences in rates of change, as noted in the analyses in preceding sections. Fuel-use intensity in services fell more in the U.S. than California, but part of this reason is the high share of area now heated by electricity in the U.S. as a whole (over 20%). By contrast, overall electricity intensity in California services grew less than it did for the country as a whole (measured relative to area), and contracted relative to value added while it grew in the U.S. Thus we believe that there is evidence that fuel and electricity intensities fell more in California than in the U.S. as a whole.

## 7.3. Conclusion: Time Trends Contrasted

Although there are many uncertainties, it appears that energy intensities in California fell somewhat faster than they did in the U.S. as a whole. Changes in the structure of the economies, which had various effects on different sectors, had overall downward affects on both economies and probably influenced California's energy use more than that of the U.S. as a whole. We cannot point to any particular policies or other causes for this slight divergence other than the acceleration of population growth in California in the late 1980s, from in-migration, which apparently drove household size upward.

# Figure 7.1
# California and U.S. Energy Use in 1990
## Comparable and Non-Comparable Sectors




Total Primary Includes miscellaneous final demand and all production losses
Gas and oil Pipelines included in "total" primary. Source: LBL database.

Figure 7.2

# California and U.S. Final Energy Use, Per Capita

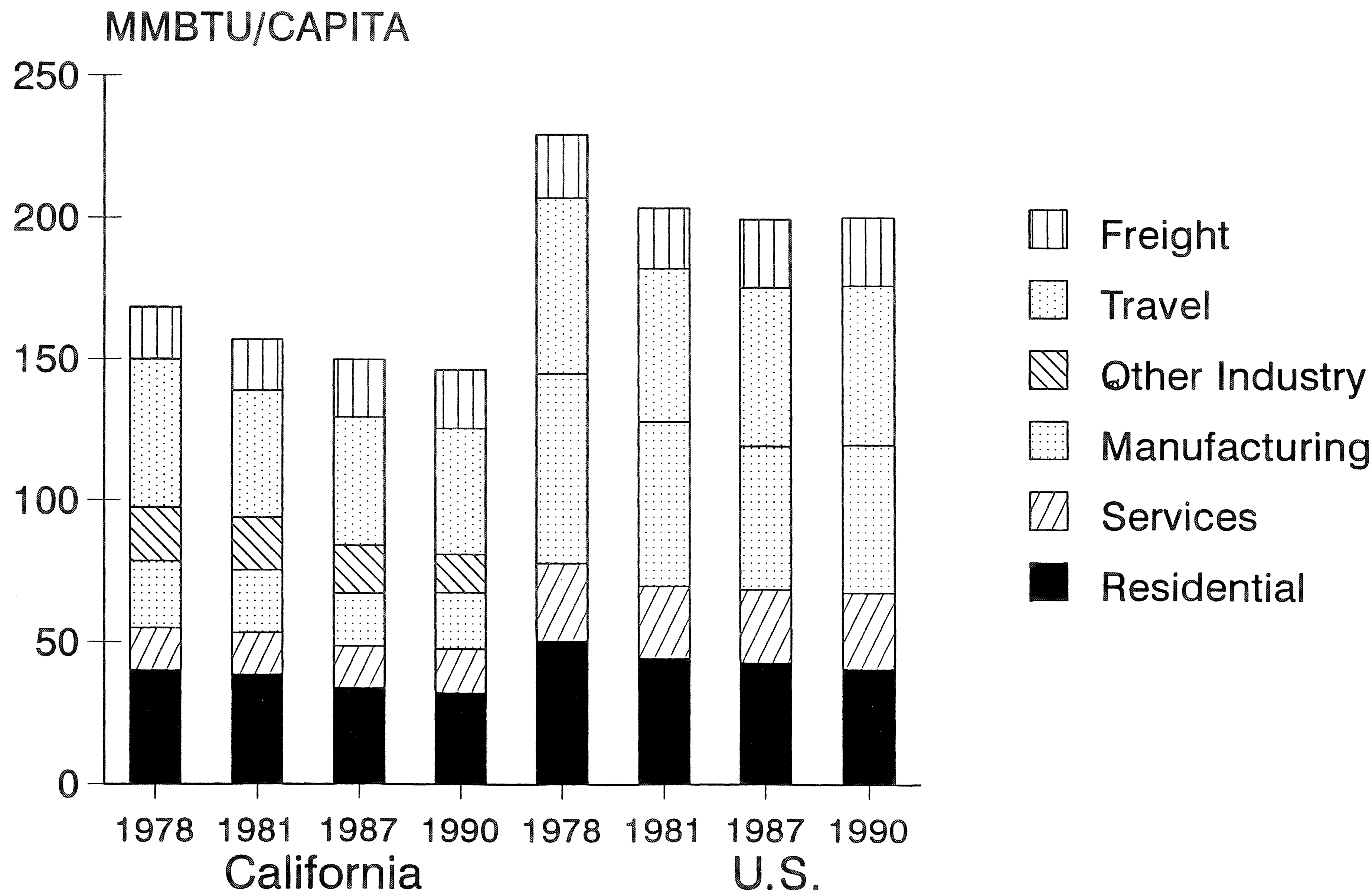
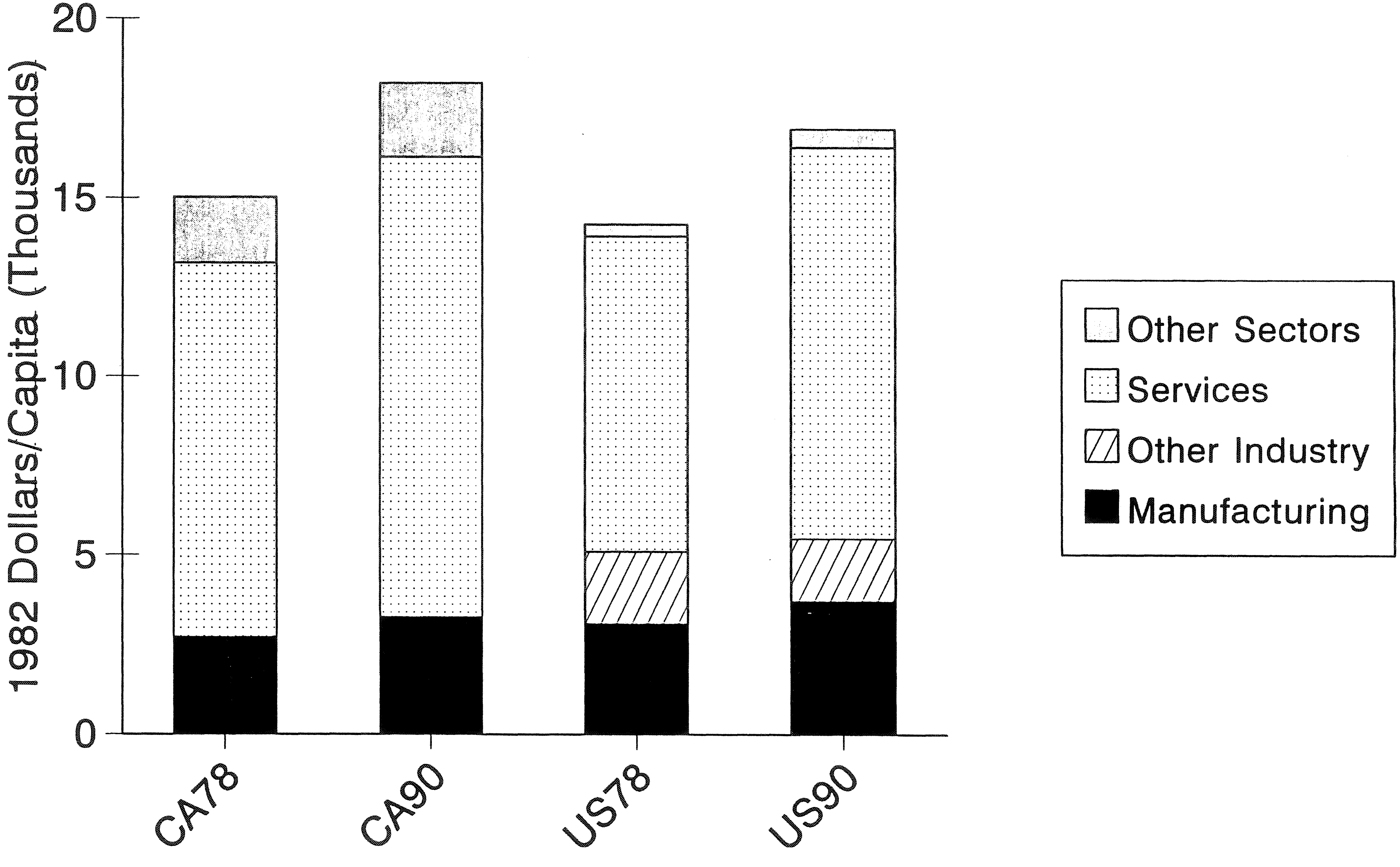
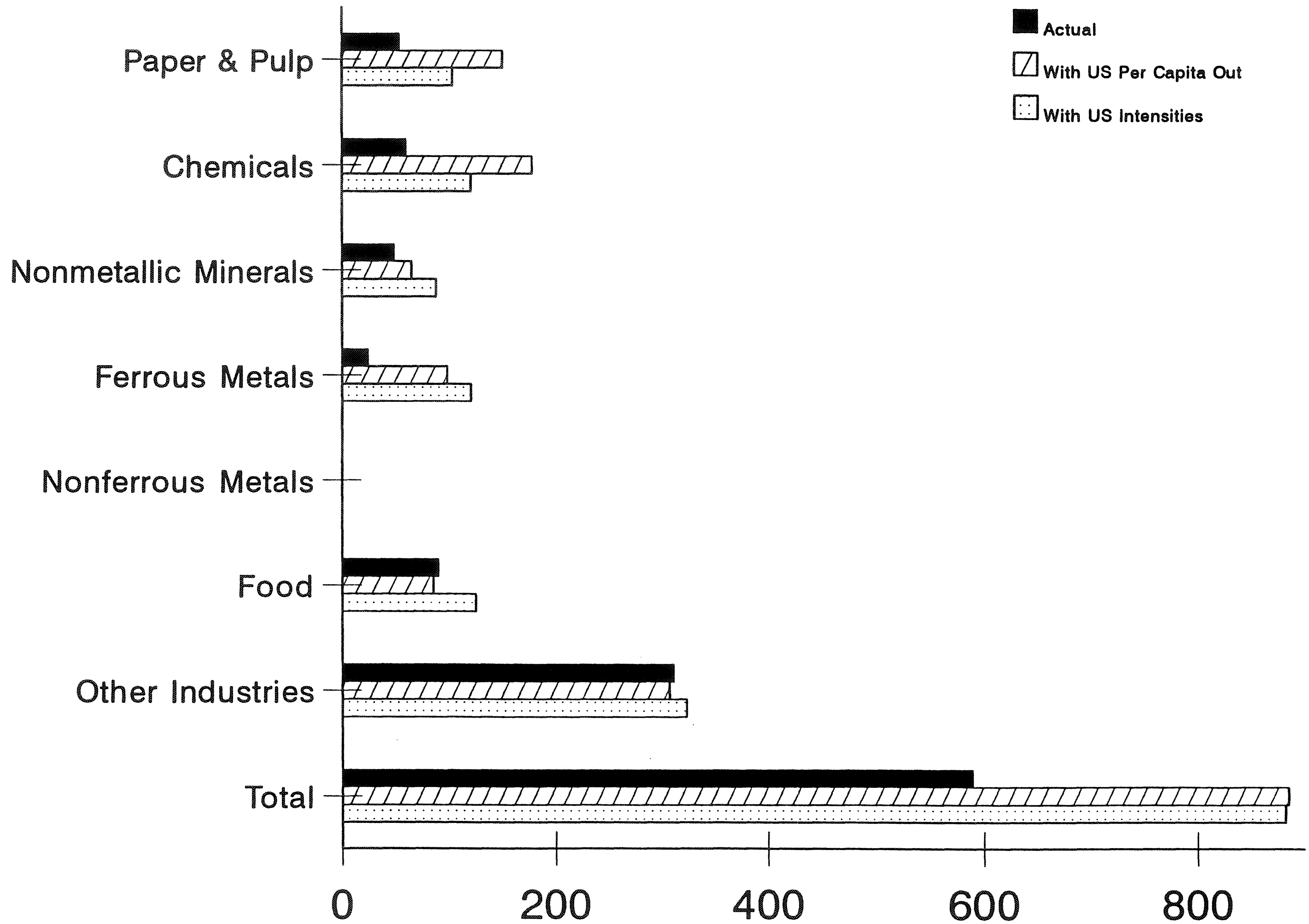


Figure 7.3

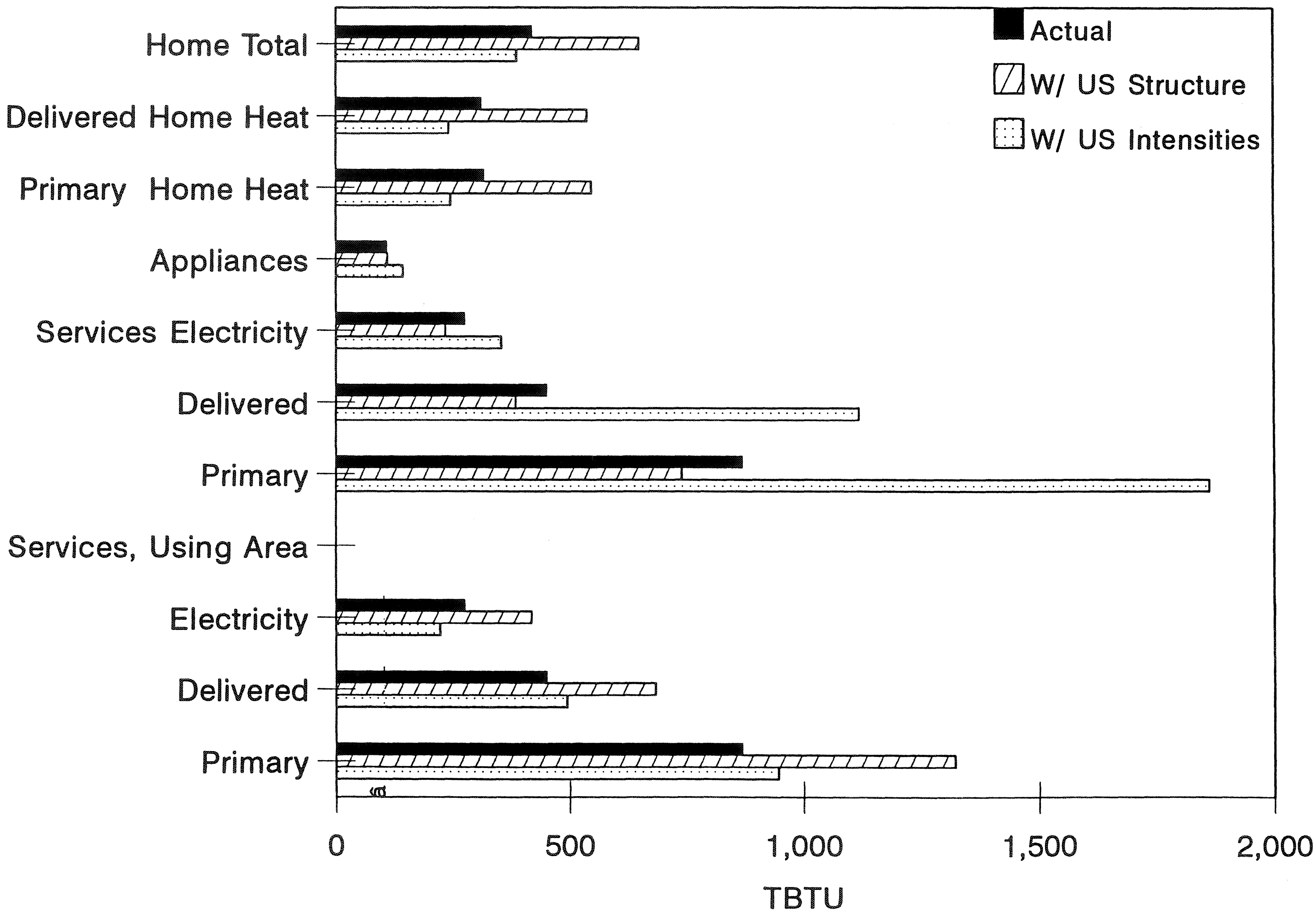
# Per Capita GDP in California and U.S.



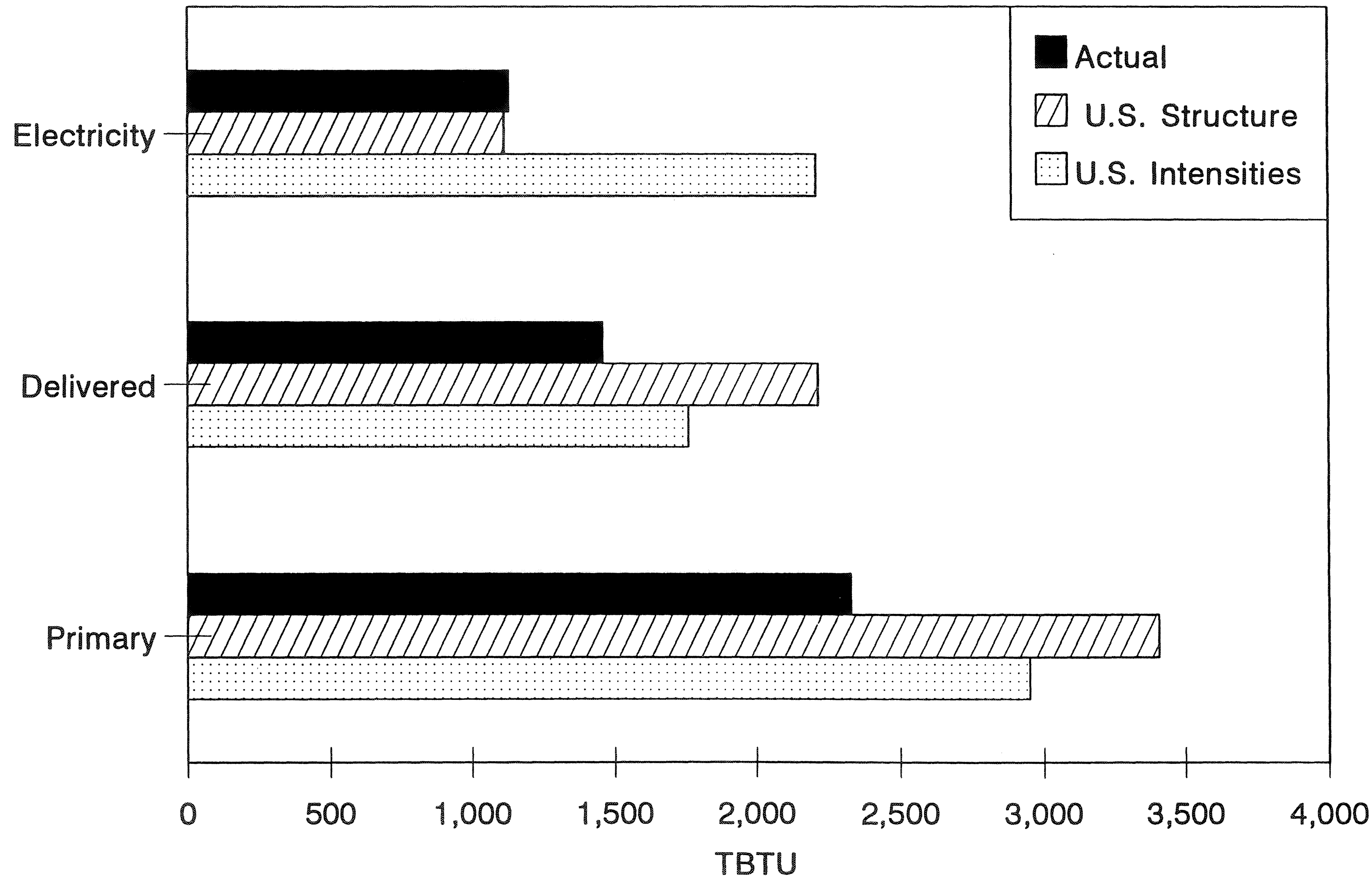
# Figure 7.4
# California Manufacturing Energy Use With U.S. Characteristics



# Figure 7.5
# California Building Energy Use With U.S. Characteristics



# Figure 7.6
# California Energy Use with U.S. Characteristics
## Sum of Sectoral Estimates (Buildings and Manufacturing)



## 8. CONCLUSIONS: HOW ENERGY INTENSIVE IS CALIFORNIA?

By any normalization, California uses less energy than the U.S. as a whole. On balance, differences in the structure of California's economy are more important than differences in energy productivity in reducing California's energy use relative to that of the U.S. as a whole. How much? In manufacturing and the household sector, structure differences reduce California's energy use by 50% relative to what would have been consumed had California the same production mix, climate, and dwelling mix and size as the U.S. as a whole. Structural differences in travel are insignificant as far as we can measure them; indeed, we have seen that California is not more dependent on the automobile than any other state on average. Structural differences for freight are impossible to measure because of a lack of data on truck freight movements, although the "state" part of freight in California appears far more reliant on trucking than the nation as a whole. Measuring the energy intensity of activities is relative: it is not meaningful to give figures without a measuring stick. Furthermore, we found that some energy intensities in California are lower than in the U.S. as a whole (manufacturing, automobiles, appliances), while others appear higher (residential water heating and lighting). Intensity differences play a smaller role in manufacturing and for appliances and actually raise California's heating demand relative to that for the U.S.

We have seen that most energy intensities in California fell by 15-20% between 1978 and 1990, slightly faster than in the U.S. Moreover, we found that the impact of structural change in reducing energy use was slightly more prominent in California than in the U.S as a whole. Overall, California's energy productivity improved slightly more rapidly than that of the U.S., and structural change reduced energy use in California at a slightly more rapid pace than in the U.S. These two factors caused the ratio of energy use to GDP in California to fall slightly faster than for the U.S. as a whole.

How important were energy prices and energy policies in forging these differences between the two regions over time? Although the overall differences between California and U.S. energy prices in most sectors are small, California faces higher fuel and electricity prices than the nation as a whole except for transportation. Moreover, the differences have been increasing, until the weighted average prices in California reached 110% of the U.S. level by 1991. This could explain part, but not all, of the differences in energy intensities between the two regions. On the other hand, the elasticity of energy use with respect to price tends to be higher for more energy-intensive activities than for less energy-intensive ones. Since California's economy is so much less energy intensive than that of the country itself, the impact of rising energy prices in California is smaller than in the nation as a whole. However, it could be argued, that California never developed energy-intensive manufacturing because California never had low-cost energy.

We can estimate how much energy was saved in California between 1978 and 1991. We calculate "savings" for any end-use or sector by multiplying the difference between 1978 and 1991 energy intensity times 1991 activity. This gives an estimate of how much more energy would have been used in 1991 had not energy intensities fallen. (In reality there is a small interaction or "rebound" term that we ignore here.) We can make this calculation for household energy uses, for electricity and fossil fuel use (relative to value added) in the service sector, for automobiles, and for each subsector of manufacturing. (We do not have meaningful energy intensities for the remainder of transportation.) All together these sectors and subsectors required slightly over 4,000 TBTU in 1991. Had not energy intensities fallen an average of 14%, these sectors would have required an additional 560 TBTU of final energy in 1991.

Were changes in energy prices or energy policies more important as the "cause" of changes in energy intensities? In Schipper, Meyers, et al. (1992) we argued that within industrialized countries in general, and the U.S. in particular, changes in prices were quantitatively more important than policies for most of the sectors in the economy. The CAFE standards in the U.S. were credited with a significant part of the reduction in the energy intensity of automobiles, a policy that affected both the U.S. and California. The most important major California policies that were not reflected in national policies were Title 24 Standards on new buildings and standards on appliances. Would the changes in intensities required by these policies have occurred in the absence of these policies? Data on efficiencies of appliances sold in California, compared to the U.S., clearly show differences due to mandatory efficiency standards. Energy characteristics of new buildings in California were also effected by regulations, even though compliance was probably incomplete. Residential useful space heat intensity in California, corrected for climate, improved over time, eventually approaching U.S. intensities. We suspect California policies as driving this change, but insufficient evidence is presented here to attribute that change unambiguously to California policies. Indirect evidence for the effectiveness of California's policies is contained in the comparisons between California and the U.S. for appliance energy intensities (Figure 2.11), and total commercial electricity consumption (Figure 3.1). More research is needed to compare California to U.S. building characteristics, and to account for differences in energy prices and other economic factors. To unambiguously attribute effects to a particular policy in a complex system requires well-designed evaluations, preferably contemporaneous with the policy.

Data regarding the percentage of energy-efficient equipment sold into California as compared to the U.S. as a whole were difficult to obtain from manufacturers because in many cases sales data are considered proprietary and/or are not tracked on a state-by-state basis. Certain manufacturers were able to provide data that supports anecdotally that California is more energy efficient than the nation as a whole.[23] For example, a leading national ballast manufacturer reported that California represented approximately 25% of the national electronic ballast market in 1994 -- this figure is up from a 20% share in 1992. For perspective, California accounts for about 10% of commercial sector electricity use nationwide. The manufacturer attributes this steady growth over the past three years to strong utility intervention with rebate programs that were better funded than in many other areas of the country. One leading window manufacturer indicated that its low-e window sales in California were 20% of national sales in recent years, even though California contains only about 10% of housing units nationwide and has a much milder winter than other states on average. A California-based manufacturer of occupancy sensors indicated that 60-70% of their sales were in-state. Finally, California's share of adjustable-speed drives were reported as 8% of the national market by one manufacturer. ASDs are application specific and may not lend themselves to California industries, but California accounts for only about 6% of industrial electricity use nationwide.

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[23] This information was collected by Miriam Pye of ACEEE in late 1994.

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## 8.1. Recommendations for Data Collection and Analysis

What does California need to know to analyze the efficiency with which energy and other resources are used? In our previous analyses of national energy use patterns and energy efficiency, we developed the indicators in Table 1 to highlight feature of both the structure and intensities of energy use. Most of these indicators could be used by CEC in ways described in this text. In this section we summarize these indicators and describe data sources, both in California and elsewhere, that would yield most of the information necessary to develop these indicators and track them over time.

## 8.2. Use of Existing Data.

The most important existing data are the State Energy Data Reports (SEDR) published yearly by the Energy Information Administration of DOE. CEC uses these data, as well as various other federal and state publications, to prepare its own energy "balances,"[25] which appear in various CEC publications. The CEC data sources and procedures were last described in detail in the 1984 *Fuels Report*. The CEC data as presented today differ in many ways from the original sources.

- The transportation sector data as published by CEC omit electricity for rail transit, trolley busses, and pipelines, and natural gas for pipelines as well. SEDS include these data.

- The utility sector data in most CEC publications fail to distinguish between electricity produced in California (or by California utilities with capacity in other states) and electricity purchased from utilities elsewhere. While the CEC practice of estimating the primary energy requirements of electricity produced from each input is itself useful, it is still important to distinguished between "domestic" and "imported" electricity, if for no other reason than to be able to compare features of production of electricity within the region regulated by CEC and CPUC and electricity produced "elsewhere."

- Industry is far too large and nonhomogeneous a sector for purposes of serious analyses of trends in energy use. One reason is because that sector, as defined by CEC, is really a residual containing leftovers from residential, services, and transportation. Another reason is that the main subsector, manufacturing, differs significantly in character from the other, smaller subsectors (mining, construction, agriculture, other utilities, etc.).

[25] See for example *California Energy Statistics*, part of the 1991 *Fuels Report*. CDC P300-91-018WP1. December, 1991.

- Manufacturing sector gas and electricity data are collected by CEC from individual utilities. Data on oil consumption have been collected for various years by CARB. Data on energy use in manufacturing were collected by the *Annual Survey of Manufacturers* for the 1970s and early 1980s. These could be reconciled with the Industry sector as provided by SEDS. (We have made this reconciliation for a few years.) A reconciliation would provide an historical estimate of energy use in construction, mining, and agriculture, and manufacturing as well. It is likely that this historical estimate could then be used to estimate current energy uses for these subsectors of Industry.

- Residential and Commercial Sector data from CEC agree closely with those from EIA. But the CEC models of homes and buildings, respectively, do not yield total gas or electricity consumption figures that agree with SEDR; in fact, for the residential sector, the CEC total is significantly lower. Indeed, it appears as if the CEC had not summed up the consumption of gas and electricity representing each of the climate regions in California to see if the total checked against either the CEC "balances" or SEDR. Reconciling models with "actual" data is important because the changes in gas use in buildings are related to the effectiveness of various state and local energy efficiency programs.

- Residential buildings reported as commercial customers by utility companies (e.g., mass-metered apartments) should be reported as residential and removed from the commercial sector energy accounting. This explicit accounting should apply to floorspace as well as to energy.

## 8.3 Other, Underutilized Data Sources.

We have identified sources of data on both activity and energy use heretofore overlooked by CEC and in some cases by other California authorities. Since both activity/structure and energy use data are needed to quantify trends in energy efficiency, we review these possibilities here.

- Transportation.

CEC should use Caltrans' H.M. Polk automobile stock survey data to estimate the MPG of new cars and light trucks bought in California. CEC should also use Caltrans' data on VMT of cars, light trucks, and heavy trucks, along with Caltrans' estimates of fuel consumption, to track fuel intensity of vehicles in each class. Comparison of total VMT of all vehicles and total fuel use, as CEC made in the 1990 *Energy Efficiency Report,* is meaningless.

Unfortunately, these data are only broad estimates that are circular. It is important that state agencies undertake from time to time a real vehicle and fuel use survey that captures both utilization (in miles) and fuel use as a function of vehicle type, place of domicile, and type of use (wholly private, etc), as exemplified by the Department of Energy's Residential Transportation Energy Consumption Survey (every three years) and the Department of Commerce Truck Inventory and Utilization Survey (every 5 years).

Beyond these modes, however, CEC should analyze energy use and activity in other modes, both for completeness and because some modes, however unimportant to total energy consumption (passenger rail local light rail and bus), arise continually in energy, environmental, and transport policy discussions. That is, both policy makers and their public and private counterparts want to know the role of these modes in hauling passengers, using energy, and generating (or saving) pollution.

Finally, various local agencies have undertaken household-based travel surveys in the past. (For example, Metropolitan Transportation Commission in the Bay Area, 1965, 1980, 1990.) There is one Caltrans report pasting together various regional surveys. But there has been no all-California personal travel survey designed to capture travel on all days of the week year 'round. Since even Denmark (population 5.2 million, barely more than half the per-capita car ownership of California) has undertaken four such surveys, California should do the same. Owing to the importance of the results to CEC, Caltrans, and CARB, this should be undertaken jointly. Most important, such a survey would capture segmented (multi-modal) trips, trips between jurisdictions, and even trips whose destinations are outside of California.

To measure local bus, rail, and subway activity and energy use, CEC and Caltrans should obtain the set of "Section 15" data on diskettes from UMTA or one of its contractors. These give vehicle miles, seat miles, passenger miles, and fuel or electricity use for almost every transit system in the country, including virtually every system in California. Admittedly, these modes account for a small amount of energy and travel, but they represent a politically important part of the transportation system.

For intercity rail, Amtrak can provide data on train miles, seat miles, and passenger miles by train for activities within California. With reasonable estimates of the activity within California (i.e., to the last stop near the border), total rail travel within California can be estimated. No data on actual fuel consumption are available, however, as these tend to be kept with each individual locomotive. However, it is possible to estimate fuel consumption from information on the number of locomotives and total train and car miles.

For intercity bus, CEC should work with Caltrans and the CPUC to obtain vehicle miles, passenger miles, and fuel use from Greyhound and other operators.

For air travel, CEC should use FAA data (available on CD rom) to calculate plane miles, seat miles, passenger miles, and trips for air travel by airline and aircraft type wholly within California, and for air travel originating in California. (We estimated the former in this report.) Using other FAA data on fuel consumption by aircraft type (or by airline), CEC can then estimate fuel use within California, for flights from California to other domestic destinations, and to overseas destinations. These estimates, plus estimates of fuel use for military and civil aviation, yield a reasonable allocation of fuel for air travel by type of travel.

The Interstate Commerce Commission provided data on rail freight hauled wholly within California and freight hauled into California permitting some estimate of interstate freight hauled on the California portion of track. In the 1984 California Transportation Atlas, compiled one time only by Caltrans (Laurel Clark, Caltrans, personal communication), presented some data on freight hauled out of California for the years 1978 to 1981.

We were unsuccessful in finding any data on ton miles hauled within California or to/from California on California roads. We also found no data on coastal or waterway freight. Moreover it is not clear if the SEDR or CEC energy data distinguish between marine fuels for "domestic" shipping or bunkers for overseas shipping (several hundred PJ or TBTU). Although California is fueled by natural gas, there are no data on ton miles of gas shipped within the state, and CEC does not count the use of gas in pipelines as part of transportation. This is unfortunate. For states where significant quantities of oil (or coal) are used for household or industrial purposes and shipped around the state by truck, rail, or ship, such shipments typically would be counted in statistics. Moreover, while fuel used by railroads, ships, and trucks moving oil (and coal) is counted in transportation, that for natural gas (and oil) pipelines is lost in Industrial or Commercial.

- Residential

The CEC should compare California data to data available from the federal government, such as SEDS. In addition, the 1993 DOE/EIA RECS survey is designed to report information by state for four states, including California. When these data become available, they will provide another useful point of comparison to the more detailed information provided by California utilities and then summed.

The CEC should develop a method for measuring 1) the sales of appliances and equipment disaggregated by energy efficiency and (2) energy-related building characteristics in California, either by working with trade associations and manufacturers or through surveys at the retail level. Simultaneously gathering consumer information would provide the best opportunity for market analysis and program evaluation.

- Services

The CEC should compare California data to data from the federal government, including CBECS.

The CEC should develop a method for measuring (1) the sales of equipment disaggregated by energy efficiency and (2) energy-related building characteristics in California, either by working with trade associations and manufacturers or through surveys at the retail level. Simultaneously gathering consumer information would provide the best opportunity for market analysis and program evaluation.

- Manufacturing

As we noted above, CARB has data on fuel use by stationary sources classified by SIC code. CEC data cover only electricity and natural gas, and therefore miss liquids, coal, and biomass, important for industries like cement, paper/pulp, and construction. With some manipulation, CARB data could be transformed to represent the entire manufacturing or even industrial sector. If California were to undertake a survey of energy use in agriculture and another for mining, it might be possible to combine all this information into estimates of energy use for manufacturing, agriculture, mining, and construction year by year.

The federal government undertakes comprehensive, triennial surveys of energy use in Commercial Buildings (CBECS), households (RECS), and manufacturing (MECS), and for household vehicles (RTECS). No state data are published, although many of the survey instruments do contain data that might be used to give some aggregate results for California. Additionally the DOC survey, Truck Inventory and Utilization Survey, provides invaluable data on this mode every five years. The *Nationwide Personal Transportation Survey* of the Federal Highway Administration investigates travel and car use patterns of individuals and households approximately every five years and, while not sampled to reflect any particular state, could be analyzed to isolate all respondents in California. Thus there are data that could be very useful for calibrating energy use efficiency in California.

CEC should negotiate with the federal authorities responsible for each survey, "buying in" to each survey to support extra data collection and processing to provide a good sample of California users. The reason CEC would have to pay for such a services is in part to compensate the federal authorities for the extra work involved to enhance the sampling. Additionally, however, federal authorities fear that if individual states were provided cross tabs of relevant data free of charge, each would demand its part from the survey. Since the surveys were not in general subject to sampling that made sense for analysis of individual states, the survey would have to be modified and the sample size increased somewhat to provide sensible results to some states. Since DOE currently does not even have the funds to properly execute its own surveys at the national level -- the RTECS survey, for example, has not received funds since 1985 to ask drivers to log their actual fuel consumption -- we can hardly expect them to respond to a request from even the largest state for special treatment.

CEC should use the National Income and Product Accounts (the GNP) by two digit sector provided by the Department of Commerce to the State Department of Finance for its main description of economic activity by sector. Use of employment or value of production, which is common in some CEC forecasts, is less satisfactory.

### 8.4. The Most Urgent Data Needs.

From the foregoing, we could propose a long list of data collecting and analysis tasks. Recognizing, however, that both resources and time are limited, we propose the following priorities for data gathering that would then permit on-going monitoring of important energy uses:

- Reconcile vehicle use, fuel use, and MPG figures;
- Estimate freight haulage of trucks by size within California and between California and other states;
- Estimate California and external air travel and corresponding fuel use;
- Estimate liquid and solid fuels (including biomass) by two digit manufacturing establishment, and estimates of all fuels and electricity by major branch of agriculture; and
- Implement a methodology for tracking sales of appliances, equipment, and building characteristics, disaggregated by energy performance, as indicators of policy impacts in the residential and commercial sectors. The CEC has several studies already in hand exploring the issues and proposing approaches.

Not surprisingly, the first three of these are related to transportation, probably politically the most important energy-consuming sector. The final sector is almost as large but not well known, particularly energy use for agriculture.

## 8.5 Formation of Indicators

With existing data, the *Energy Efficiency Report* can report on vehicle MPG by vehicle type, stock appliance unit energy consumption, intensity of household and commercial sector space heating at the state level, energy intensity of two-digit manufacturing activity, and energy intensities of bus and rail transit, all for 1991. If the foregoing recommendations for data gathering are carried out, then the NEXT *Energy Efficiency Report* could include:

- A more reliable breakdown of energy intensities in manufacturing, agriculture;
- Energy use, activity, and energy intensities in all major modes of transportation (including an important but difficult allocation of transportation energy uses between in-state and interstate (or international) movements;
- Energy uses and intensities in the household and commercial sectors that are consistent with total consumption of all fuels and electricity in those sectors, not simply the source counted in the sectoral and regional models; and
- Comparisons of the distributions of energy efficiencies of equipment and appliances sold in California to national distributions.

TABLE 2

**Data Summary**

| Company | Products | Response |
|---|---|---|
| GE | CFL's, T8s | data NA |
| Magnetek | electronic ballasts | product shipped to wholesalers, ultimate consumer unknown |
| Unenco | occ. sensors | 60 - 70% sold to CA in most current year |
| Marathon | e-e motors | data NA for CA (overall, 22.6% of motors sold are e-e) |
| Reliance | e-e motors | 80% of product shipped to orig. equip. manufacturers, ultimate consumer unknown |
| ABB | ASDs | 8% currently, has been increasing |
| Lennox | CAC (SEER > 12) | state data NA |
| Trane | CAC (SEER > 12) | data proprietary |
| Advance | e-e ballasts | CA % of e-e ballasts (in units)<br>1992 20%<br>1993 ~23%<br>1994 ~25% |
| Pella | low-e windows | 20% sold into CA |
| Anderson | low-e windows | ~1.5% sold into CA |

All others were called and/or received letters but did not respond with data.

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