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ENERGY CONSUMPTION IN CALIFORNIA'S BUILDINGS SINCE 1990: AN INDICATORS ASSESSMENT OF KEY FACTORS

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) Program established the **California Climate Change Center** to document climate change research relevant to the states. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

Energy Consumption in California's Buildings Since 1990: An Indicators Assessment of Key Factors. is the final report for the Preliminary Economic Analyses of Climate Change Impacts and

Adaptation, and GHG Mitigation project (contract number 500-02-004, work authorization number MR-006) conducted by Lawrence Berkeley National Laboratory.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

This study sought to quantify the effect of various factors in shaping energy consumption trends in California's buildings. It drew from the end-use energy consumption data in the California Energy Balances (CALEB) database, disaggregated data from the California Energy Commission, and economic activity data, using an "energy indicator" approach. *Indicators* refer to quantitative data that reveal something about the relationship between energy consumption and underlying drivers. Analysis for the service and residential sectors was limited to electricity and natural gas, which account for more than 95 percent of the energy consumed in each sector. In the service sector, total site energy consumption increased approximately 18 percent from 1990 to 2003. This was less than the growth of three activity indicators: service value added, service employment, and service floor area. In residential buildings, total site energy consumption increased 9 percent from 1990 to 2004. The saturation of most major appliances and end uses remained relatively steady, indicating that California may be nearing near total saturation for many end uses. The exceptions are central air conditioning, dishwashers, and electronics. The share of electricity increased in both sectors. The increasing shares of electricity in both sectors led primary energy consumption to grow faster than site energy consumption.

Keywords: CALEB, California Energy Balances Database, energy indicators, energy consumption, service sector, residential sector, decomposition analysis

Executive Summary

Introduction

In an earlier project for the California Energy Commission, Lawrence Berkeley National Laboratory undertook an in-depth study of California's energy supply and consumption. As the culmination of this work, Berkeley Lab produced the California Energy Balances (CALEB) database. This project builds on work discussed in a previous report, *Development of Energy Balances for the State of California* (CEC-500-2005-068), which described the data sources and the methods used to piece several sources of data into a comprehensive picture of how energy flows through the California economy.

Project Purpose

This project sought to better understand some of the key factors driving energy consumption in California's services- and residential-sector buildings.

Project Objectives

The study drew from the consumption data assembled in the California Energy Balances database and combined it with economic, end-use, and other sector-specific data to characterize and quantify relationships between energy use and end uses in California's services- and residential-sector buildings. The study quantified the effects of various factors in shaping energy consumption trends by using energy indicators. The term *energy indicators* refers to a broad array of analytical approaches used by energy researchers to better understand the driving forces behind differences in energy consumption across time.

Project Outcomes

Service Sector Results

The service sector analysis covers the years 1990 to 2003. For service sector buildings, three types of indicators were explored: the ratios of energy consumption to (1) service employees, (2) floor area, and (3) service sector value added. Total service sector site consumption of natural gas and electricity increased approximately 18 percent from 1990 to 2003, although the growth was not smooth.[1] In contrast, services value added[2] increased almost 37 percent from 1990 to 2003.

Energy consumption remained flat or dropped in response to the recession of the early to mid-1990s and to the electricity crisis of 2001. Defined in terms of energy per square foot, the

[1] Note that the site energy values are for electricity and natural gas only. They exclude liquid and solid fuels, for which disaggregated data were not available. However, natural gas and electricity account for over 95 percent of services site energy in California.

[2] *Value added* refers to the monetary value added in the service sector.

total sector-wide energy intensity was about 96,500 British thermal units (Btu) per square foot in 2003, which was 3 percent lower than the 1990 level of 99,800 Btu. Energy per square foot seems to be rising at about 0.3 percent per year, but this does not appear to be a robust indicator.

Interestingly, Btu per dollar of value added has shown a more consistent trend; declining by a little more than 1 percent per year. This trend is statistically more robust than Btu per square foot (Btu/sq ft). This is not surprising since, over the short term, activity levels will generally be much better reflected by value added than by square footage, which cannot change quickly in response to activity levels. The final intensity indicator, energy per employee, exhibits a slight decline of about 0.3 percent per year, but like Btu/sq ft, this indicator may not be particularly reliable.

Aggregate energy intensities such as those discussed above present the results of sector-level analyses, but they do not indicate the contribution of structural subsector changes on total energy consumption. Intensities within subsectors may show very different trends that are masked at this aggregate level, so the services sector was disaggregated into eight subsectors and the value added intensities were calculated for each.

Many subsectors showed impressive declines in energy intensity. The intensities of the three most energy-intensive subsectors in 1990—universities and schools, restaurants, and hotels and motels—fell 34 percent, 26 percent, and 12 percent, respectively, by 2003. However, analysis of all of the subsectors indicated that structural changes overall have worked to drive up energy consumption due to the increase in value added shares represented by energy-intensive subsectors such as restaurants and food and retail stores.

Residential Sector Results

The residential sector analysis covered the period from 1990 to 2004. Several factors drive energy consumption in the residential sector: population, per capita floor area, saturation of various end-use devices (that is, the percentage of the households using them), efficiencies of end-use devices, and occupant behaviors. Electricity and natural gas account for a very large share of total energy, almost 98 percent in 2001, the last year with complete data for the other fuels. Thus, the analysis focused on those two energy sources.

Several trends have affected the level of total energy consumption in the residential sector. From 1990 to 2004, California's population increased nearly 21 percent. The total number of California housing units actually increased faster than the population, increasing over 23 percent. Per capita gross state product increased more than 25 percent, compounding the increased demand for energy services. However, despite the growth in population and incomes, total gas and electricity consumption between 1990 and 2004 increased only 8 percent, although the rates of growth differed sharply between natural gas and electricity. Natural gas consumption grew at only 0.2 percent per year on average, but electricity consumption grew at 1.6 percent.

Sector-wide indicators have fallen sharply since 1990. Energy consumption per unit of gross state product has decreased the most among these indicators, by 28 percent, while Btu per capita declined 9.7 percent.

Water heating is responsible for nearly 40 percent of total residential natural gas demand, second only to space heating. Water heating intensity has decreased slightly since 1990.

Total residential climate-corrected electricity consumption increased more than 12 percent. However, in per capita terms, consumption fell a total of 7 percent. The largest single electrical end-use category is "miscellaneous," due to its high saturation rate. Lighting accounts for about 9 percent of residential electricity consumption, so lighting requirements must account for a significant share of the miscellaneous category. Since this category aggregates several different end uses, it is difficult to say exactly what the key drivers of this increase are, but growth in home electronics, computers, and other home office equipment likely accounts for most of this growth.

Refrigerators are the largest single source of end-use consumption of residential electricity in California. The total energy use of refrigerators declined in large part due to the sharp drop in the unit energy consumption of refrigerators in recent years. From 1990 to 2004, the unit energy consumption of refrigerators declined nearly 17 percent.

Central air-conditioning is the largest single non-appliance end use. It accounted for a little over 5 percent of total electricity demand in both 1990 and 2004. However, the saturation of central air-conditioning grew significantly over this time. By 2004, over a third of all California households were equipped with central air-conditioning. Offsetting the increasing saturation of central air-conditioning was the 18 percent decline in its unit energy consumption, which reflects both the effect of appliance standards on the air-conditioning units themselves and the effect of building codes on improving building shell insulation.

On a per-household basis, electric space heating is a large energy consumer; however, the saturation of electric space heating remained quite steady at about 13 percent—much lower than the national average of 29 percent. As with air conditioning, the unit energy consumption of space heating declined sharply.

Summary and Conclusions

Total service sector site energy consumption of natural gas and electricity grew from 404 trillion Btu (TBtu) to 475 TBtu from 1990 to 2003, an increase of nearly 18 percent. Three aggregate drivers of service sector energy consumption were examined: (1) service employees, (2) floor area, and (3) services value added. Floor area was found not to be a robust short-term indicator. Value added and employment both correlated more closely with energy consumption, and value added was selected for further analysis as an indicator. The relative increase in energy consumption was significantly less than the increase in service sector value added. Thus, the aggregate intensity ratio of site energy per value added (in real dollars) declined by 14 percent.

Structural changes in the service sector tended to increase energy consumption, particularly with the increased value added shares of restaurants and food and retail stores. However, the intensities of almost every subsector (except miscellaneous services) fell, with the intensities of several subsectors declining by 25 percent or more. Without disaggregated end-use data, it is difficult to say what is responsible for the decline, but building codes must have played a consequential role in helping to reduce demand growth.

Total service sector consumption of primary energy grew faster than site energy, increasing 23 percent. This growth was due to the increasing share of electricity in the total site consumption. Excluding minor fuels, the share of electricity rose from 55 percent in 1990 to 61 percent in 2003. Due to the greater primary energy required to produce and deliver electricity, a trend toward greater electrification will increase primary energy consumption relative to site consumption.

Overall residential energy consumption grew 9 percent between 1990 and 2004. In contrast, two major drivers of energy demand grew much faster. If energy use per capita had remained constant, population growth alone would have increased residential energy consumption nearly 21 percent. Since per capita gross state product also increased over 25 percent, per capita demand for energy services was also growing with larger new homes and increasing saturation of central air-conditioning, hot tubs, and electronics. Together, these two factors would be expected to increase residential energy consumption faster than population growth if no other changes had taken place. Given this, the relatively small growth in residential energy consumption is impressive.

The increasing saturation of some end uses helped to drive up energy consumption. The most important end use whose saturation increased significantly is central air-conditioning. Countervailing trends helped to hold total energy consumption steady. This is largely due to stringent appliance energy consumption standards and building codes that went into effect during this time period. Declines in the unit energy consumptions of space heating, air-conditioning, water heating, refrigerators, and freezers are saving significant amounts of energy. Indeed, if the 1990 unit energy consumptions of these devices had not changed, residential site energy consumption would have been approximately 10 percent higher in 2004. These standards and codes are particularly important, since the landlord-tenant problem places the efficiency of many end uses out of the control of the residents who use the devices.

1.0 Introduction

In an earlier project for the California Energy Commission (Energy Commission), Lawrence Berkeley National Laboratory (Berkeley Lab) undertook an in-depth study of California's energy supply and consumption. As the culmination of this work, Berkeley Lab produced the California Energy Balances (CALEB) database. A report describing the data sources and the methods used to piece several disparate sources of data in to a comprehensive picture of how energy flows through the California economy was released in 2005 (Murtishaw et al. 2005).

While CALEB and the accompanying report assemble and balance a wide array of energy data, no effort was made to explain the observed trends in energy consumption. The current study draws from the consumption data assembled in CALEB and combines this with economic data, end-use data, and other sector-specific data to better understand some of the key drivers behind the observed consumption of energy in California buildings. These building are classified into two major sectors: residential and services.

This study quantifies the effects of various factors in shaping the trends in energy consumption by using "energy indicators," which are generally ratios that reveal something about the relationship between one phenomenon and another. The indicators described in this report serve as a preliminary step in quantifying the contributions of different factors on energy data that will be presented in a forthcoming decomposition report. Decomposition analysis is a technique that has been employed by several energy analysts since the 1970s (Ang and Zhang 2000; Schipper et al. 2001). The technique has been applied to commercial buildings and residential buildings (Krackeler, Schipper, and Sezgen 1998; Haas and Schipper 1998; Unander et al. 2004). By indexing certain drivers to a base year value, it is possible to show how energy consumption (or carbon dioxide [CO_2] emissions) would have changed had all other factors been held constant.

A general approach taken in decomposition analysis is to define energy consumption as a function of activity, structure, and intensity. In the manufacturing sector for example, *activity* can be defined as the total value added of all manufacturing industries, *structure* refers to the shares of value added contributed by each industry, and *intensity* is the amount of energy required to produce a unit of value added by each industry. The indicators used in this report can be grouped into the same categories, and different approaches to defining these indicators will be examined for both the residential and services sectors.

2.0 Indicators Approaches and Uses

2.1. Definition of Indicators

The use of the term "energy indicators" refers to a broad array of analytical approaches used by energy researchers to better understand the driving forces behind differences in energy consumption across time or among different energy-consuming entities. At a broad level, human activity data such as population, travel, and economic growth indicate fundamental drivers of energy consumption. Frequently such data are used to normalize energy consumption, to show how energy consumption changes in relation to human activity. As Schipper et al. (2001) explain,

> Energy indicators describe the links between energy use and human activity in a disaggregated framework. [A]nalysts commonly construct ratios of energy consumed per unit of a given activity (energy intensities) in order to calculate changes in energy efficiency. Indicators help to show how energy use is shaped by economic and technical factors, such as energy prices, economic growth, and new technologies. (p. 50)

When working with energy indicators, it is helpful to understand the concept of energy services. When consumers use energy, they are really consuming the services that energy provides rather than the energy per se. For example, consumers do not purchase kilowatt-hours (kWh) for the sake of using kWh. Rather, consumers desire heating for their homes, mobility, lighting, and other services. In this report, activity and structural factors are sometimes said to affect the demand for energy services, which can be provided at varying levels of energy intensity (the amount of energy consumed per unit of energy service provided).

2.2. Approaches to Constructing Indicators

Energy indicators can be constructed at various levels of aggregation. A very crude, but frequently used, indicator is total energy consumption per unit of gross domestic product (GDP). Changes in this ratio over time tell us little about efficiency since the relationship between energy consumed and dollar of GDP changes due to numerous structural changes as well. For example, economic output may shift toward lighter industries or services, freight transit may shift from one mode to another, the quantity and types of household devices may change over time as the economy grows, the fuel mix used to generate electricity may change, and personal transport activity is not captured in GDP.

Disaggregated indicators that more closely match the energy consumed to the activity to which it is most closely associated (e.g., final energy consumed per ton of steel produced) provide a more accurate representation of intensity. They also enable the tracking of structural changes at a finer degree of resolution. However, highly disaggregated indicators require highly disaggregated data. Data limitations often require the use of less desirable indicators.

2.3. Use of Indicators Analysis

Energy indicators help to unravel the effect of multiple factors on total energy consumption over time. As an example, in the residential sector it has been observed in many countries that residential energy consumption has increased steadily (Unander et al. 2004). Population growth obviously contributes to this trend, and in California at least, residential energy use normalized to population has remained fairly constant. The demand for energy services per capita has grown due to structural factors like larger home sizes and increasing ownership of certain household devices such as central air conditioning, dryers, and home electronics. Disaggregated residential sector energy indicators can help to demonstrate how increased end-use efficiencies can offset changes in home size and appliance ownership.

3.0 Service Sector

3.1. Composition of Service Sector

The service sector encompasses most non-industrial economic activity. The Energy Commission datasets provide data at several levels of disaggregation. The service sector as defined for this report consists of end uses categorized as "commercial" in the Energy Commission data. The term "services" is used because many of the activities included (e.g., K–12 education, colleges, or government services) are not truly commercial in nature. Excluded are entities that comprise the Energy Commission's "Transportation, Communications, and Utilities" (TCU) sector, because these entities are involved in specialized activities that do not fit neatly into the framework of other service activities.

Service sector buildings are grouped according to the principal activity that occurs in them. The sectorization used for this study consists of the following categories:

- K–12 Schools
- Colleges and Universities
- Restaurants
- Food Stores
- Retail Outlets
- Non-Refrigerated Warehouses
- Refrigerated Warehouses
- Health Care Facilities
- Hotels and Motels
- Offices
- Miscellaneous Services[3]

It is important to understand energy consumption in the services sector, since it accounts for a large share of the growth in California's electricity demand. In a previous study on California electricity use, Brown and Koomey (2003) pointed out that electricity consumption in commercial buildings increased 84% between 1980 and 2000, representing nearly half of the total growth in electricity consumption during that time.

3.2. Data Sources

Energy consumption data are taken from CALEB, with additional data for more recent years provided by the Energy Commission (CEC 2006). The Energy Commission collects electricity and natural gas data at a highly disaggregated level consisting of hundreds of North American Industrial Classification System (NAICS) codes. These are then aggregated into six major sectors (plus "unclassified"). Service activities consist of two major sectors:

[3] *Miscellaneous services* include a wide variety of activities such as movie studios, rental and leasing services, theaters, and casinos.

"commercial" and TCU. The Energy Commission's commercial sector consists of the service activities where the energy consumption occurs mostly in buildings. The energy data for the commercial sector are disaggregated into the subsectors shown above. Recent energy data from 2002 forward split offices into two different building types: large and small offices. Since previous data were not so disaggregated, the two building types were combined from 2002 to 2004.

Data on liquid and solid fuels are also available from the Energy Information Administration's State Energy Data System (SEDS) (EIA 2006). However, these data are not included in this analysis for two reasons. First, the data are only available for the sector as a whole—no disaggregation is provided. This does not allow the data on the consumption of these fuels to be integrated with the subsectoral analysis possible with electricity and natural gas. Second, these other fuels constitute only a small share of the service total. According to the SEDS data, natural gas and electricity account for over 96% of the site energy consumed by California's commercial sector.

The Energy Commission provided data on commercial floor space disaggregated into different building types by the subsectors shown above. Like the more recent energy data, office floor space is divided into small and large offices. However, since the earlier energy data lack this detail, the floor space data on offices were also combined into one series.

Data on gross state product (GSP) were obtained from the U.S. Dept. of Commerce, Bureau of Economic Analysis (BEA, 2005). Data series were provided in real 2000 dollars. The data on service sector value added were adjusted to exclude the contributions of the TCU sector. Data for 1990 to 1997 were based on Standard Industrial Classification (SIC) classifications, while those from 1998 on are based on NAICS. Thus, there may be a slight distortion in the trends due to a break in the series between 1997 and 1998. At the time of this analysis, the real dollar series only extended to 2003, limiting the range of the analysis to that year. Note that the GSP data are not disaggregated for the services sector at the same level of detail as the energy and floor space data. Due to this data constraint, a different categorization consisting of eight categories was necessary to calculate subsectoral intensities based on value added. Labor market data are from the California Economic Development Department (CEDC 2006). The series on total services employment was adjusted to exclude TCU sector employees.

3.3. Total Energy Consumption and Aggregate Indicators

3.3.1. Activity Indicators

Various data could be used as an indicator of the activity level of the service sector. One key driver of service sector energy demand is economic growth. California's service economy grew more than 36% in real terms from 1990 to 2003, an average annual rate of growth (AARG) of 2.4% (see Table 1). The rate of growth increased dramatically after 1995 when California began to emerge from a recession, with the services value added growth rate increasing from 0.3% from 1990 to 1995 to 3.8% from 1995 to 2003. The service economy did not grow quite as fast as the entire economy, which grew 43%. The rapid economic growth of

the 1990s was driven largely by gains in the manufacturing sector and information services such as data processing and software. Despite the gains in information services, the service sector share of the California economy declined from 68.7% in 1990 to 65.4% by 2003.

Table 1. Activity drivers of service energy demand with average annual growth rates

Indicator	Unit	1990	1995	2000	2003	AARG, 1990–2003 (%)
Total GSP	Billion 2000$	956	971	1,297	1,369	2.8
Services GSP	Billion 2000$	657	666	823	896	2.4
Floor Area	Million sq ft	4,895	5,285	5,622	5,977	1.5
Services Labor Force	Thousands	9,121	9,477	11,095	11,315	1.7

Since floor space determines the amount of area that must be heated, cooled, lighted, or even refrigerated, floor space is an important determinant of demand for energy services. Total services floor area grew 22%. Labor force, another way to measure service activity, grew at nearly the same rate as floor area (24%). Because value added increased faster than both floor area and labor force, services GSP per square foot and per employee both increased. Although services value added did not grow as quickly as the economy as a whole, the labor force share rose from 70.9% to 76.6%.

3.3.2. Total Energy Consumption and Aggregate Intensities

While the services economy grew 36% and floor area grew 24% from 1990 to 2003, total site energy use only rose 17.6%, from 404 TBtu to 475 TBtu, during this time, an annual growth rate of 1.3%. Electricity use increased much faster than natural gas use, 29.6% versus 2.7%. Since electricity and natural gas consumption increased at much different rates, primary energy consumption grew faster than site energy, at 23.4%, as is often the case when a sector experiences a trend toward greater electrification. A trend toward a greater share of electricity in the service sector has been prevalent throughout the industrialized world. A previous study noted that in 13 Organisation for Economic Co-operation and Development (OECD) member countries, the average share of electricity in the services sector rose from 24% to 44% over the period from 1973 to 1995 (Krackeler et al. 1998). In California, the share was already 55% in 1990, but it may be that electrification had reached a certain level of saturation[4] by the mid-1990s as the share has stabilized at around 60% to 61%.

Figure 1 shows the total site energy consumption by subsector and the 1990 and 2003 shares by subsector. The largest subsector is offices, which accounted for a little over 25% of site energy in both 1990 and 2003. The next largest is miscellaneous services, whose share has grown from 13% to 16%. The only other subsector to have used more than 10% of the total site energy in both years is restaurants, which accounted for about 13% of the total in both years.

[4] See the discussion of saturation in Section 4.4.2.

The effect of the 2001 electricity crisis is readily apparent in Figure 1. An interesting phenomenon that also shows in the data is that efficiency investments or behavioral changes that occurred in response to the crisis seem to have continued dampening total energy demand, because total consumption still had not risen to the 2000 peak by 2003.

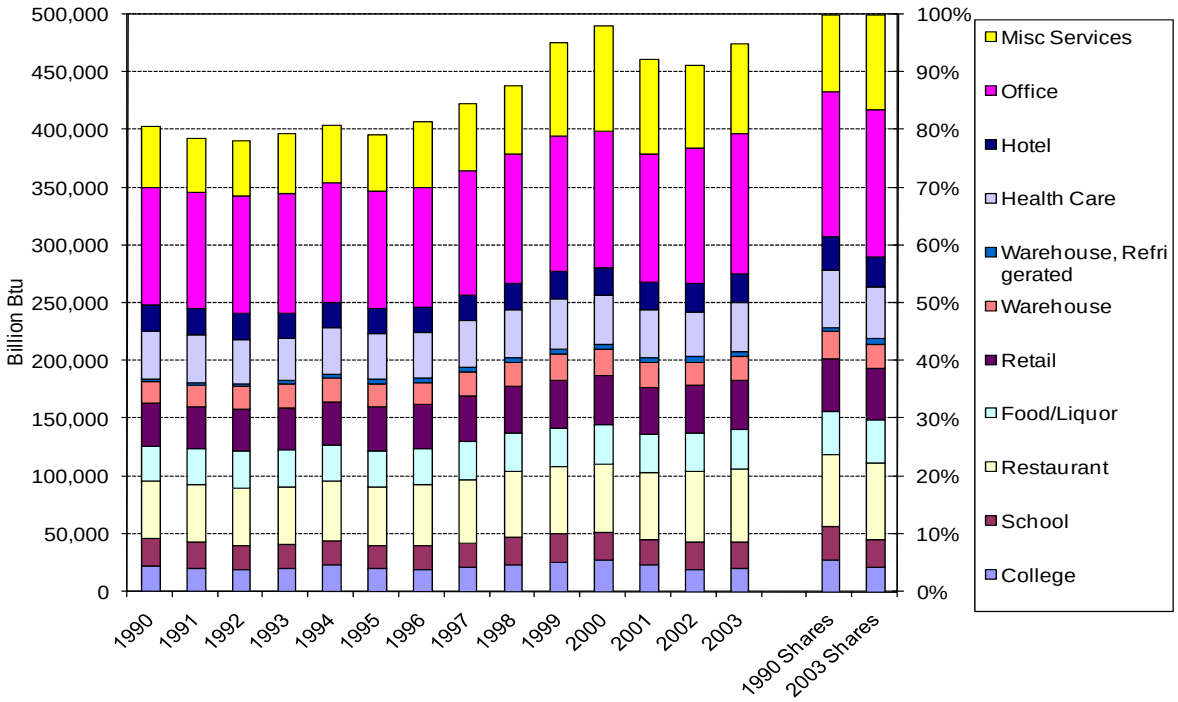

Figure 1. Total site energy consumption by services subsector with 1990 and 2003 shares

Total site energy was plotted against the activity data from Table 1, and simple regressions were run on each series. The results, depicted in Figure 2, only cover the years from 1990 to 2000 because the electricity crisis of 2001 creates an anomalous dip in the scatter plot that is not related to the activity drivers examined here. The trend lines show that employment and value added seem to provide better fits to the energy consumed than floor space. This is logical because floor area is not immediately responsive to need, especially in the downward direction, so that as activity declines in response to a recession the perceived aggregate intensity will go down as well. (In other words, commercial space is not immediately demolished in conjunction with an economic downturn.) Likewise, intensities may go up, at least in the short term, as activity increases. Then they will tend to level off, or even decline, as more floor space is built to meet the needs of increased activity.

The effects of the recession of the early 1990s are apparent in the graph, where for each data series, site energy consumption (y-axis) and the underlying drivers (x-axis) tend to increase with time. Very little movement in either energy consumption or the activity indicators occurs in the first few years. As California's economy emerged from the recession, both activity and energy consumption grew in tandem. A difference can also be observed between floor area on the one hand and value added and employment on the other. Construction of

commercial floor space continued in the early 1990s despite the downturn in service activity. Stagnation in employment, value added, and energy consumption causes the points of these series to cluster together in the early 1990s, while the floor area series dips. This supports the observation that floor area, due to its "chunkiness" (i.e., its inability to quickly respond to changes, since it takes time to construct buildings), may not track short-term changes in energy consumption as well as employment and value added.

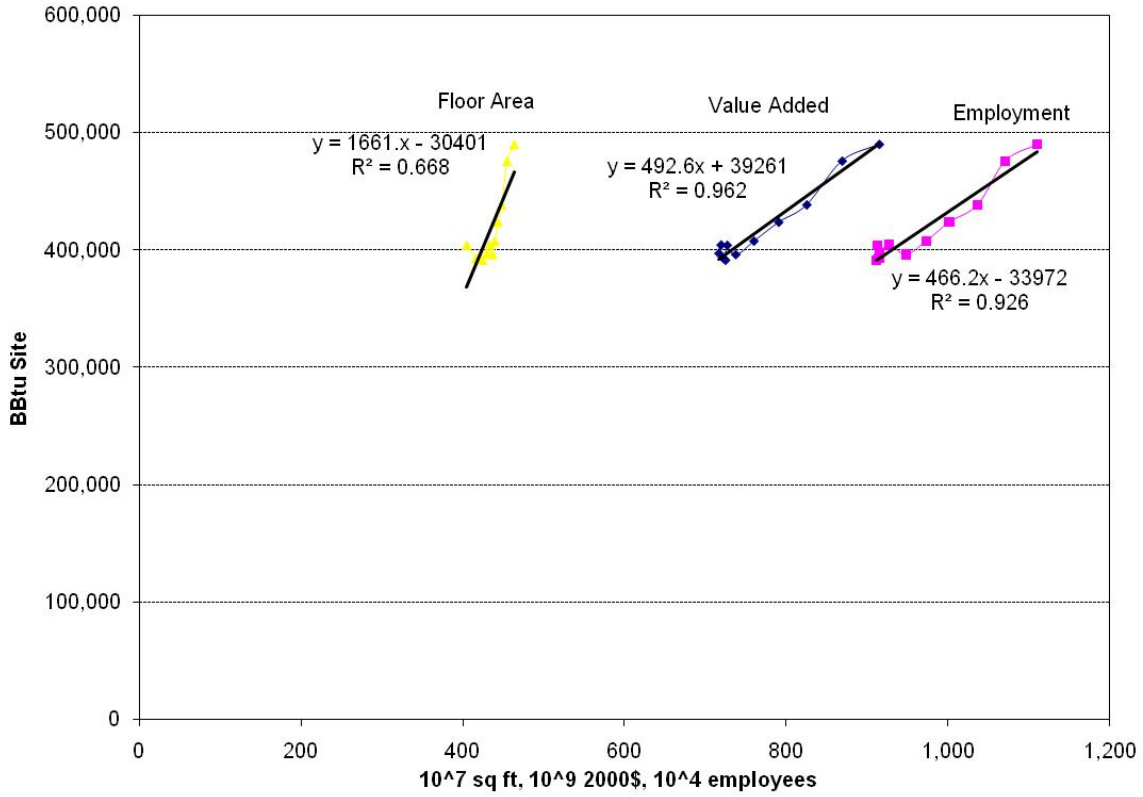

Figure 2. Scatter plot of activity data and total site energy, 1990 to 2000

Aggregate intensity indicators were also calculated from the activity data, and the results are shown in Figure 3. Aggregate intensity was calculated in three ways using each activity data series: per square foot of floor area, per year 2000 dollar of services value added, and per service sector employee. The total sector-wide area-based intensity was about 96,500 Btu per square foot in 2003, which was 3% lower than the 1990 level of 99,800 Btu, but the exponential trend line shows that energy per square foot seems to be rising at about 0.3% per year. Due to the variance in the trend line (R^2 is only 0.14), and given the results from Figure 2, this does not appear to be a robust indicator. As seen in Figure 2, the Btu per square foot ratio fell at first and then remained relatively steady during the recession of the early 1990s. Then as the economy picked up, the intensity began to climb.

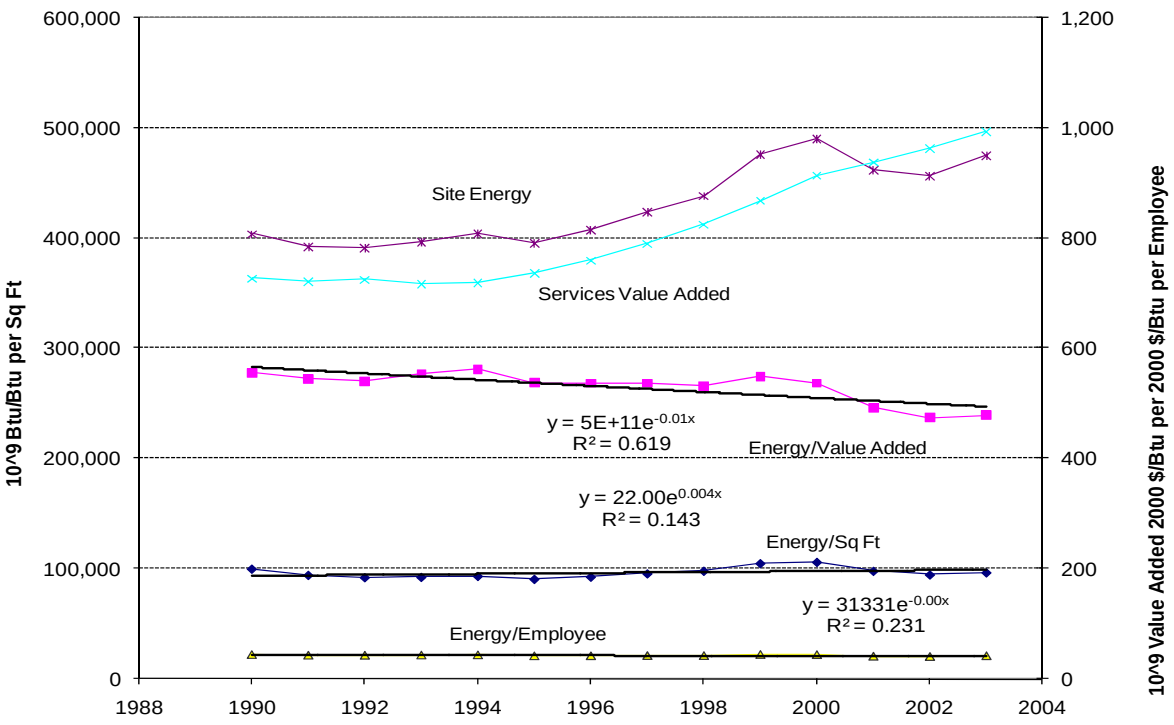

Figure 3. Services value added and aggregate intensity indicators

Interestingly, Btu per dollar of value added has shown a more consistent trend. Figure 3 depicts the Btu/$ trend line scaled to the right-hand axis. Intensity defined in this way has declined by a little more than 1% per year, from 556 Btu per 2000$ to 478 Btu per 2000$. The better fit of this trend compared to energy usage is indicated by the much higher R^2 of the trend line (R^2 is 0.62) compared to the Btu/sq. ft. This is not surprising, since over the short term, activity levels will generally be much better reflected by value added than by square footage. The final intensity indicator, energy per employee, exhibits a slight decline of about 0.3% per year. This indicator is not in widespread use for indicator or decomposition analyses of the service sector, so this indicator is not developed further in the disaggregated analysis that follows.

3.3.3. Other Important Drivers of Services Energy Consumption

There are many other important drivers of energy consumption in the services sector. Aggregate intensities such as those shown above do not indicate the contribution of structural changes in the subsectoral shares of the sector on total energy consumption. Additionally, intensities within subsectors may show very different trends that are masked at this aggregate level. Fuel-specific and subsector analyses are described below. However, the role of other drivers could only be accurately determined with more disaggregated data. For example, weather affects demands for heating and cooling, but without a reliable estimate of energy used for space heating and cooling, it is not possible to determine the effect of annual fluctuations in heating degree-days (HDD) and cooling degree-days (CDD).

Similarly, ascribing energy savings to building shell improvements is not possible without the heating and cooling energy estimates.

End-use equipment also changes over time in ways that may affect energy use. As one example, office buildings have experienced a large infusion of electronic office equipment over the past twenty years (Kawamoto et al. 2001). The presence of computers, computer peripherals, fax machines, and servers has had a significant effect on electricity demand, but quantifying the effect of this shift requires highly detailed end-use data.

3.4. Disaggregated Site Energy Intensities and Structural Changes

Since the energy consumed per unit of value added seemed to be the most robust intensity indicator for the sector as a whole, this intensity indicator is the focus of the disaggregated analysis. However, some observations are also made concerning the usage of energy per square foot. The amount of total site energy per year 2000 dollar of value added used by the eight economic subsectoral categories is shown on Figure 4. Several interesting observations can be discerned from this figure. First, the individual subsectors show some startling trends. Many subsectors show impressive declines in energy intensity: the intensities of the three most energy-intensive subsectors in 1990—universities and schools, restaurants, and hotels/motels—fell 34%, 26%, and 12%, respectively, by 2003. Intensity of food & retail stores, the fourth most energy-intensive subsector, fell by 34%, and by 2003 had fallen just below miscellaneous services, which experienced an increase of 3%. However, miscellaneous services encompasses so many diverse activities that these changes could be due as much to structural shifts within this category as to any real intensity changes. Of the less energy-intensive subsectors, office and health care showed less pronounced declines, perhaps because as lower intensity services, there are fewer measures that result in large savings. The exception is total warehouse, whose intensity fell 29%.

Second, total services intensity lies among a cluster of subsectors that are much less energy intensive than the other sectors. This means that these sectors account for a disproportionate share of the value added to the extent that the much higher intensities of the other sectors have little effect on the sector average. This has implications for the structural effects on sectoral energy consumption, as discussed below.

In terms of structural effects, it is worth noting the large discrepancies in energy intensities among the service subsectors. The energy intensities of the most energy-intensive subsector (universities/schools) and the least intensive (offices) differed by a factor of 35 in 1990. Because the energy intensity of universities and schools fell so sharply, by 2003 the difference had fallen to a factor of 25. Still, with such large differences, a shift over time in shares of value added can have a significant effect on total sectoral energy consumption.

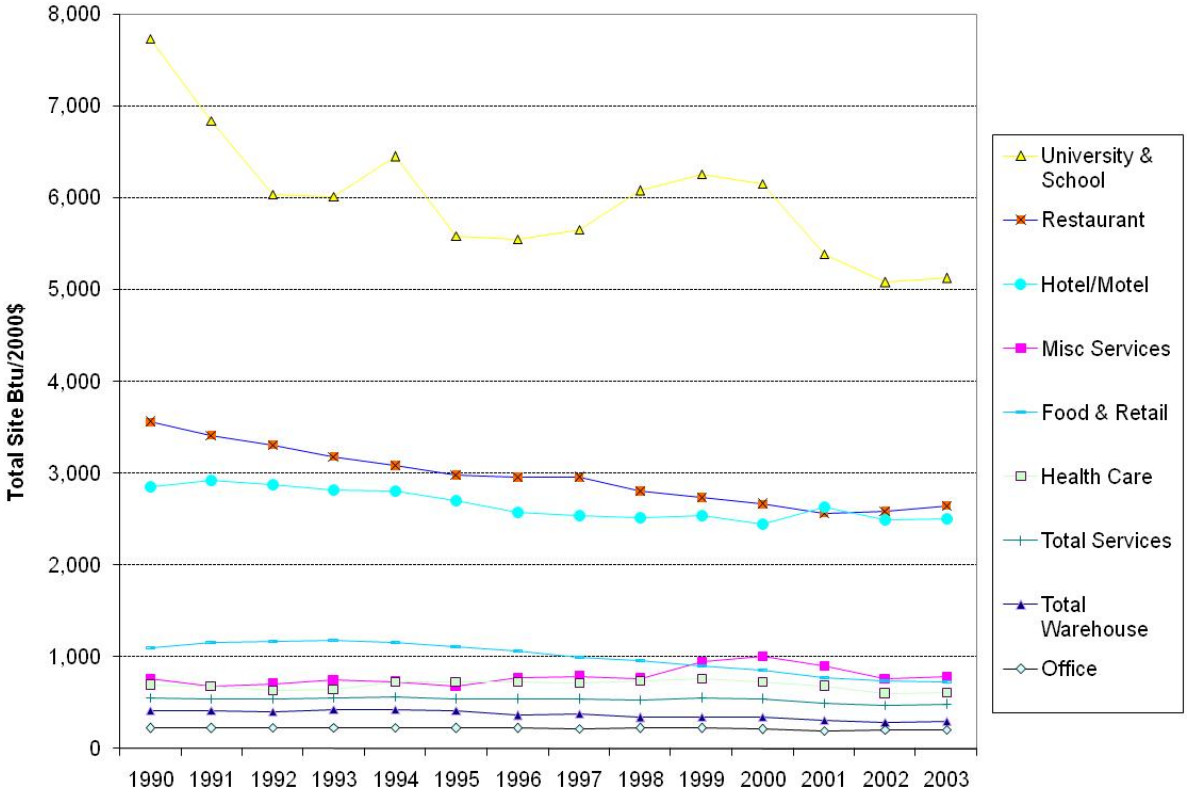

Figure 4. Disaggregated site intensities, Btu per 2000$

Table 2 indicates what effects structural changes have had on energy consumption in the service sector since 1990. The three most energy-intensive subsectors only accounted for less than 4% of the total 1990 value added. These subsectors gained a small increase in the share of value added by 2003. The total share of the six subsectors above the sector average in 1990 was 30.1%. By 2003, the share had climbed to 31.8%, indicating that structural changes overall has worked to drive up energy consumption. The final row in Table 2 shows the total weighted average sectoral intensity for 1990 and 2003. The sectoral average fell 14%. Additionally, a counterfactual 2003 sectoral intensity is shown using 2003 value added shares at frozen 1990 intensities. This weighted average shows that structural change alone would have driven the sectoral average energy consumption to 589 Btu per 2000$, an increase of 6%.

Table 2. Subsectoral intensities (Btu/2000$) and changes in value added shares and intensities

Subsector	1990 Intensities	2003 Intensities	% Change in Intensities	1990 Share (%)	2003 Share (%)
Universities & Schools	7,734	5,125	-34	0.8	0.8
Restaurants	3,556	2,645	-26	1.9	2.4
Hotels/Motels	2,848	2,503	-12	1.1	1.0
Food & Retail	1,101	726	-34	8.4	10.7
Misc Services	765	789	3	9.7	10.0
Health Care	689	612	-11	8.1	6.9
Total Warehouses	418	298	-29	7.0	8.4
Offices	222	204	-8	62.9	59.8
Sector Average [a]	556	478	-14	N/A	589[b]

[a] Due to rounding, the averages shown are slightly different than values calculated from the table.
[b] Hypothetical sector average with 2003 value added shares at frozen 1990 intensities.

3.5. Fuel-Specific Intensities, Fuel Shares, and Primary Energy

3.5.1. Overall Growth and Aggregate Intensities

In addition to the trends in total energy consumption and consumption by fuel, it is also useful to look at the trends in fuel shares between electricity and natural gas. This is of interest for two key reasons. First is the implication of a trend toward electrification on total primary energy consumption. Since as much as two-thirds of thermal energy is lost as waste heat in the process of converting fossil fuels to electricity and about 8% of electricity is lost to resistance in the transmission and distribution of electricity, the use of one unit of delivered electricity results in a total primary consumption of roughly three times as much energy. Using data from SEDS (EIA 2006), which estimates the losses due to transformation, transmission, and distribution, a primary energy factor can be derived from the ratio of the sum of electricity consumed and electricity losses to electricity consumed. This factor was calculated from 1990 to 2002, the most recent year available in the SEDS data. The average primary energy factor from 1990 to 2002 was 3.28, which was used for 2003.

A second, and related, reason to be aware of fuel mix trends is that, except for regions with an extremely low-carbon electricity generation mix, the direct use of natural gas produces fewer greenhouse gases (GHGs). California has a relatively low-carbon electricity generation mix, even considering the imports of electricity from Southwestern states where the generation mix is dominated by coal. A previous study (Marnay et al. 2002) estimated that the average release of CO_2 per kWh of electricity consumed in California in 1999 (including imports of electricity from other states) was 0.40 kilograms (kg). An equivalent consumption of natural gas (3,412 Btu) would release approximately 0.18 kg of CO_2. Thus, even with California's relatively clean power mix, a shift toward a greater share of electricity in the fuel mix will tend to increase CO_2 emissions.

Figure 5 shows total site energy use for both natural gas and electricity. While consumption of both has increased since 1990, consumption of electricity has grown at a much faster rate. Total electricity consumption grew from 223 TBtu (65.4 terawatt-hours, TWh) in 1990 to 313

TBtu (91.7 TWh) in 2003. The growth rate is over 2% per year. The growth rate for natural gas, however, was about 1%. This has resulted in the share of electricity growing from just over 55% of site energy in 1990 to over 61% by 2003. This has pushed up the growth in primary energy compared to site energy. While total site energy grew nearly 18%, primary energy consumption grew over 23%.

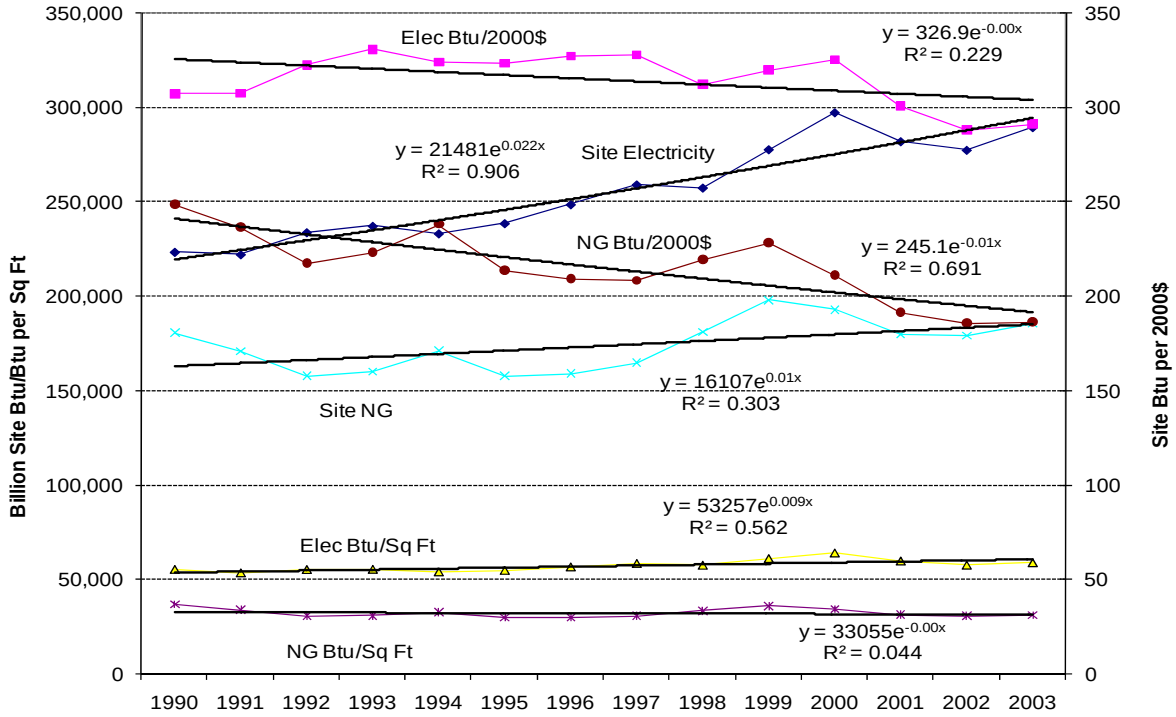

Figure 5. Total services natural gas and electricity use and aggregate intensities

Another interesting difference appears in the intensities of natural gas compared to electricity. While intensities of both decline in terms of value added, electricity intensity per square foot has increased since 1990. This increase is largely due to an anomaly in the data concerning miscellaneous services. This subsector exhibits a large increase in electricity consumption after 1998, which can be seen in Figure 4.

4.0 Residential Sector

4.1. Characteristics of the Residential Sector

In 2004, there were over 12.8 million housing units in California (Census 2005). Of these, 64.4% were single family residences (SFRs), 31.1% were multifamily residences (MFRs), and 4.5% were manufactured (mobile) homes. The California housing stock has increased over 23% since 1990. Several trends have acted on the level of total energy consumption in the residential sector. As per capita incomes increase, the size of the home increases. An International Energy Agency study found that in the United States the dwelling area per capita increased from roughly 470 square feet to 650 square feet between 1973 and 1998, an increase of 38% (Unander et al. 2004). Similar gains were seen in per capita dwelling area in several other industrialized countries. The per capita gains were the result of both growing home sizes and a reduction in the number of occupants living in each dwelling. Unfortunately, a reliable time series of residential floor space for California was not available, so it is not known exactly how these trends have affected residences in the state.

Larger homes drive demand for space heating and conditioning (and refrigeration to a certain extent), but other factors have also affected energy use. Rising ownership of major appliances, air conditioner, and electronics has also put upward pressure on energy demand.

Running counter to these pressures has been the declining energy intensity (amount of energy required per unit of energy service delivered) of many of these end uses. Appliance standards have brought down the annual unit energy consumption of many appliances. In some cases, the decline has been dramatic. Building codes have required builders to meet certain minimum energy performance standards. Even though they have not yet captured a large share of the residential market, the greater availability of compact fluorescent lights (CFLs) has allowed both home owners and renters to substantially lower their lighting energy demand. The subsequent sections will demonstrate how these trends have shaped overall energy demand.

4.2. Data Sources and Description

The primary data source is the Energy Commission's database of electricity and natural gas sales (CEC 2006). This database provides a highly disaggregated accounting of natural gas and electricity deliveries by utility coded by either the Standard Industrial Classification (data from 1990 to 2001) or the North American Industrial Classification System (2002 to 2004 data). Data on population are from the U.S. Census (Census 2004). Gross state product data are from the Bureau of Economic Analysis (BEA 2005). Data on saturation and estimated energy consumption by end use are from the Energy Commission's energy forecast model data sets (CEC 2005a).[5] One important discrepancy to note is that the totals from reported utility sales differ from the sums of the individual end uses since the end-use data are

[5] Due to the availability of end-use data and the differences in the uses of electricity and natural gas, the two fuels are analyzed separately for the disaggregated indicators.

estimates. The end-use data are also designed to show a steady trend and are thus in essence implicitly corrected for year to year weather fluctuations. On average, the sum of the end-use data for natural gas is close to the reported total sales while the electricity figures are about 4% higher.

4.3. Total Energy and Aggregate Indicators

4.3.1. Activity Data

One of the most important drivers of residential energy consumption is the demand for housing, which is in turn driven by population. From 1990 to 2004, California's population grew from 29.8 million to 35.9 million, an increase of nearly 21%. Over the same period, the U.S. population increased by 18%. The total number of California housing units increased faster than the population, from 10.4 to 12.8 million, an increase of over 23%. This means that the average number of occupants per dwelling dropped from 2.87 to 2.80. However, this may not reflect a real trend toward fewer occupants per household, since that ratio has fluctuated between 2.75 and 2.90 since 1980.

All else held constant, total energy use would be expected to increase by roughly the same amount as the housing stock. However, another important macro driver of residential energy consumption, per capita income, contributes to increasing demand for energy services. Generally, as incomes rise, more energy services will be demanded, as higher incomes are used to buy more living area, appliances, and electronics. In real terms, per capita GSP rose from $32,120 to $40,272 in year 2000 dollars, an increase of over 25%.

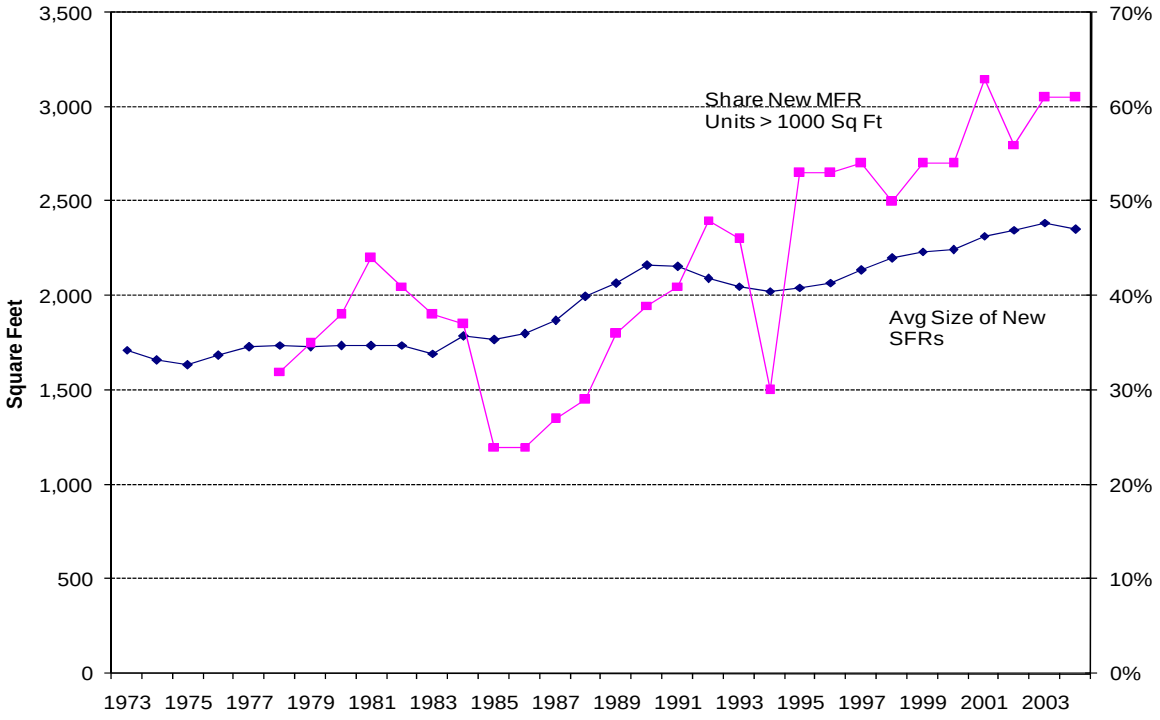

Figure 6. Trends in new housing unit sizes in the Western Census region

An indicator of how increasing per capita income indirectly affects the demand for energy services is the trend in new housing unit sizes. Larger home sizes increase the demand for both heating and cooling services. Unfortunately, statewide time series data on the average unit size in the entire stock of housing could not be found for California. However, census data for the Western Census region provide an indication of the magnitude of this effect. The "Characteristics of New Housing" database provides average and median home sizes completed each year for SFRs and shares of square footage by five different square footage ranges for MFRs (Census 2006). Figure 6 depicts the trends in both data series. These data show that the average new SFR built in 2004 (2352 square feet) was 9% larger than the average home built in 1990. The share of MFR units built that are 1000 square feet or more also increased from 39% to 61%.

4.3.2. Total Energy Consumption and Aggregate Intensities

Figure 7 shows the total consumption of energy in the residential sector (excluding firewood), as well as total consumption of natural gas, electricity, and liquefied petroleum gases (LPG). Insignificant quantities of distillate fuel oil and kerosene are also consumed, but these are not shown on the chart. Since the recent data for LPG and other minor fuels are not available, a separate line for the sum of natural gas and electricity is also shown. The analysis focuses on electricity and natural gas for the same reasons as in the service sector. Disaggregated data are not available for the other fuels, and electricity and natural gas account for a dominant share of total energy, almost 98% in 2001, the last year with complete data for the other fuels.

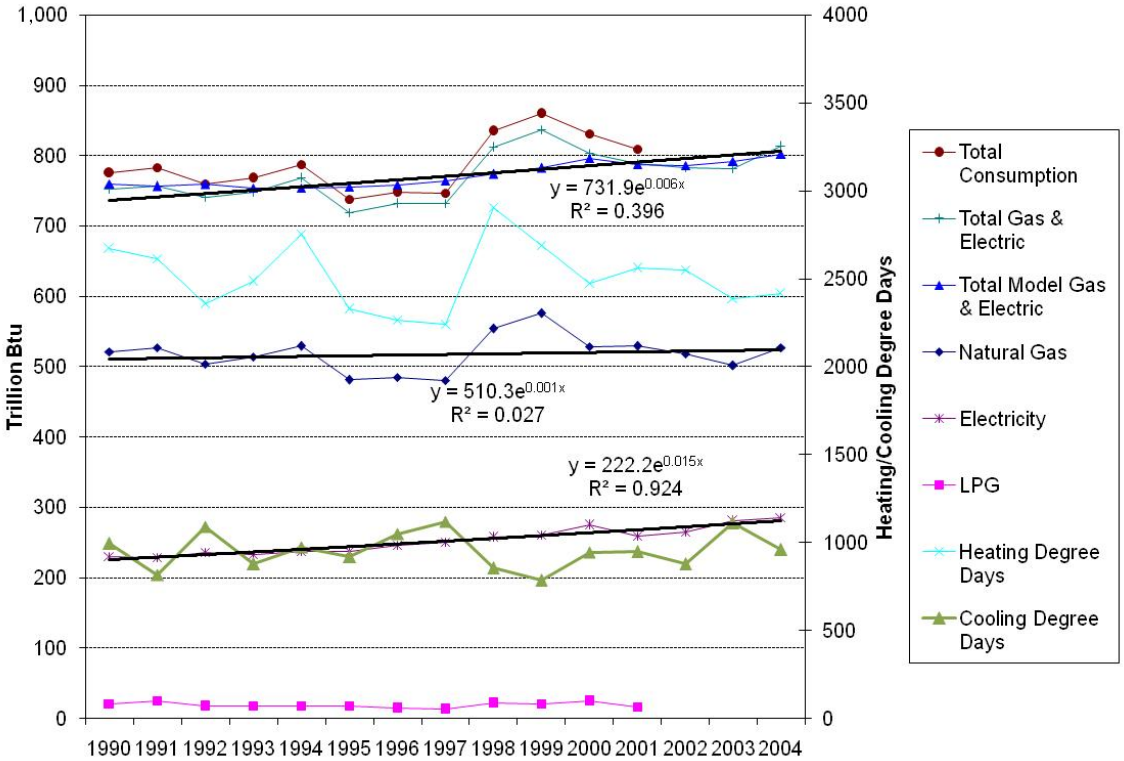

Figure 7. Total residential energy consumption by major fuel

Total reported gas and electricity consumption grew from 752 to 813 trillion Btu (TBtu) between 1990 and 2004. As the exponential regression line in Figure 7 shows, this amounts to an annual growth rate of about 0.6%. The total consumption of natural gas and electricity from the model data is also shown. This line closely tracks the trend line. It is interesting to note that the rates of growth have differed sharply between natural gas and electricity. While natural gas grew at only 0.2% on average, electricity consumption grew at 1.6%. This is largely due to the increasing saturation of key electrical end uses such as central air conditioning, dishwashers, and computers, while the saturation of natural gas end uses has remained relatively stagnant.

A stark difference appears not only with respect to the growth rates of gas and electricity consumption, but also the pattern. A glance at the chart reveals that the year-to-year quantity of natural gas consumed has been erratic. Indeed, the exponential regression line shows the R^2 value to be negligible. The main variable that affects the year-to-year consumption of natural gas is weather. About half of residential natural gas consumption in California is weather-related: space heating, air conditioning, hot tub heating and swimming pool heating. Figure 7 also plots the annual average HDD, and the correlation between gas use and HDD is apparent. In contrast, the trend in electricity consumption has been much steadier, with the exception of the drop due to the 2001 electricity crisis. The consistency in growth is also borne out by high R^2 value of the trend line. In contrast, most of the consumption of electricity is for interior uses that are not weather dependent. Less than 15% of electricity is consumed for the weather-related uses described above. This is due in part to relatively low saturation of electrical space heating in California compared to many other states. Figure 7 shows that there is relatively little correlation between the electricity consumption and cooling degree days.

Table 3. Aggregate residential sector energy intensity indicators

Indicator	Unit	1990	1995	2000	2004	% Change, 1990–2004
Total Res Gas and Electric per Capita	M Btu/cap	24.9	23.6	23.2	22.5	-9.7
Total Res Gas and Electric per Household	M Btu/HH	71.4	68.1	64.3	63.1	-11.7
Total Res Gas and Electric per GSP	Btu/2000$	776	764	608	559	-28.0

HH = household

Table 3 provides an example of sector level aggregate indicators. To mitigate the effect of weather variability, the model data were used for natural gas. However, due to the consistent bias in the model data for electricity and low degree of weather dependency in electricity consumption, the reported electricity data were used. These three indicators are useful for demonstrating the relationship between energy consumption and some of its key drivers. One encouraging trend is that per capita energy consumption fell a little over 10%. Note though, that 2004 was a warmer year than 1990. With the same number of HDDs, total energy consumption in 2004 would have been approximately 3% to 4% higher, erasing much of this decline. Energy use per household fell by a similar percentage, but this is not surprising since the housing stock grew at about the same rate as population. These trends only diverge if there is a significant change in the average number of occupants per

household. In contrast to these two indicators, the ratio of energy consumed per unit of GSP fell much faster. This may be an indication not only of improvements in energy efficiency but also of near-total saturation for some of the larger end uses. In other words, as incomes rise, consumers may be spending the extra income on devices and end uses that are less energy intensive. Keep in mind, these indicators are too broad to provide much explanatory power. The disaggregated indicators described below shed more light on why these ratios have declined.

The enactment of standards for appliances and other end uses has been an important factor in helping to reduce overall energy intensities in the residential sector. The Energy Commission estimates that as of 2003, appliance standards were reducing electricity consumption by approximately 12 TWh below what would have occurred otherwise (CEC 2005b). California was the first state to enact appliance standards, doing so prior to the adoption of standards at the federal level. The first standards were adopted by the Energy Commission for refrigerators, air conditioners, and air conditioning heat pumps in 1976 with standards for furnaces, water heaters, shower heads, and faucets adopted the following year (Martin 1997). Standards for refrigerators were tightened in 1980 and again in 1987 (Rosenfeld 2003), and other standards were also adopted in the 1980s (Martin 1997).

Table 4. Effective dates of federal residential end-use standards since 1990

End Use	Effective Date	First Revision	Second Revision
Clothes Washers	1994	2004	
Clothes Dryers	1994		
Dishwashers	1994		
Refrigerators and Freezers	1990	1993	2001
Room Air Conditioners	1990	2000	
Water Heaters	1990	2004	
Ranges and Ovens	1990		
Fluorescent Lamp Ballasts	1990	2005	
Central Air Conditioners	1992	2006	
Furnaces	1992		

With the passage of the National Appliance Energy Conservation Act in 1987, state standards were preempted for products covered by federal regulation. Table 4 lists the effective dates for federal efficiency performance standards for residential products. Many standards first went into effect in the early 1990s, although several standards have been revised in recent years. Since many of these products have lifetimes of 10 to 30 years, the savings in any year depend on the turnover of stock. Thus, the effect of the standards set in the early 1990s (or earlier) manifest in declining average energy consumptions taking place across the time period studied.

The Title 24 building codes have also contributed substantially to energy savings in California by reducing the need for heating and cooling. These codes stipulate minimum standards for insulation, windows, and other factors affecting energy consumption. Building code efficiency standards for were first consolidated by the Energy Commission under Title

24 in 1980 and are updated periodically. The most recent revision occurred in 2005. The Energy Commission estimates that by 2003, building codes enacted since the 1970s were reducing annual electricity consumption by approximately 10 TWh (CEC 2005b).

4.4. Natural Gas Trends[6]

4.4.1. Total Consumption and Aggregate Intensities

Total consumption of natural gas is shown disaggregated by end use in Figure 8. Total residential natural gas consumption in 2004 was 527 TBtu, only 1% higher than the 1990 level of 522 TBtu. Natural gas consumption per capita has fallen 15% since 1990, roughly 1.1% per year. Due to the implicit climate corrections applied to the data, total consumption here shows a much smoother pattern than what appears in Figure 7. This figure shows clearly that space heating and water heating account for the bulk of residential natural gas demand. The rightmost bars of the chart depict the consumption by each end use for 1990 and 2004 as a share of total for each year. The two major end uses account for over 80% of consumption in both years. Space heating is analyzed in more detail in the next section.

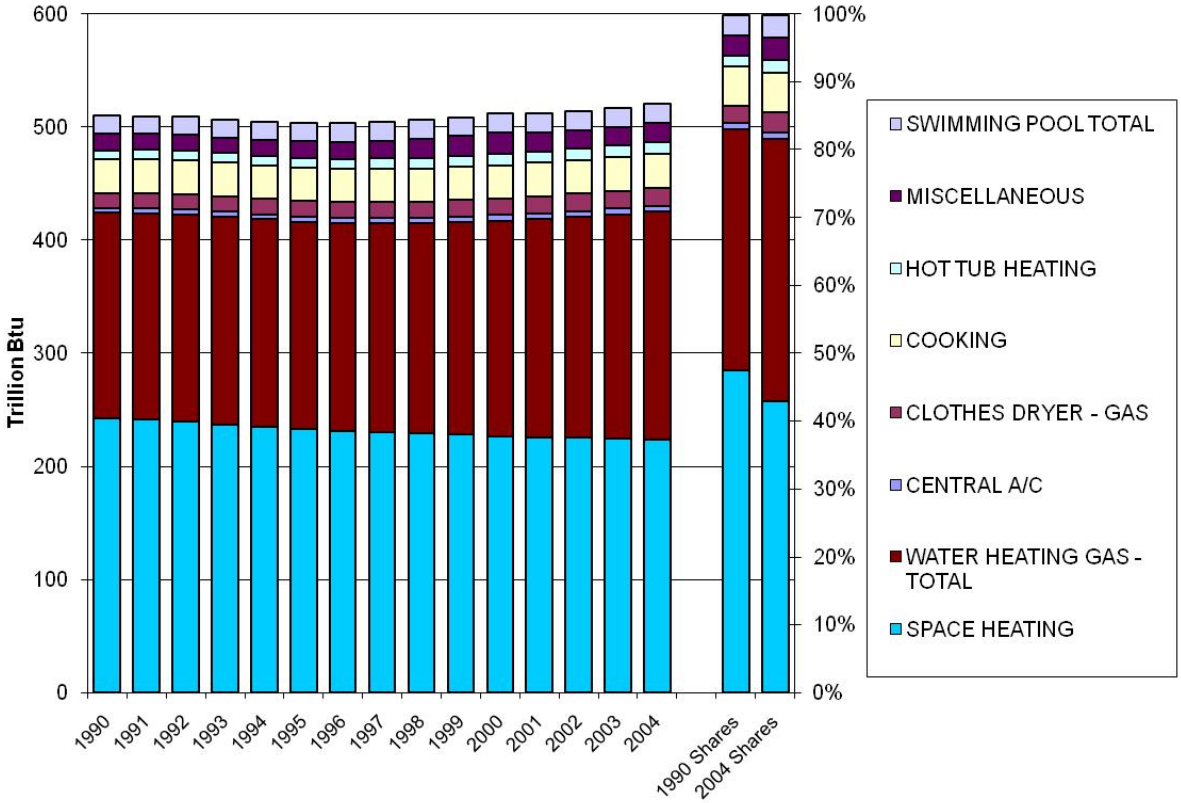

Figure 8. Total natural gas consumption by end use with 1990 and 2004 shares

[6] All of the results presented in this section are based on the Energy Commission's forecasting model data sets (CEC 2005a).

4.4.2. Space Heating and Other Non-Appliance End Uses

For a given number of households, an end use drives energy consumption in two different ways: through unit energy consumption (UEC) and saturation. *Unit energy consumption* is the amount of energy consumed by an end use per year. End uses also affect energy consumption as a function of their presence in households. The *saturation* of an end use refers to the ratio of the number of that device to the number of total households. Generally, this number will be between 0% and 100%, that is, the percentage of households having that type of device. For refrigerators that ratio is higher than 100% since virtually every household has at least one refrigerator and many have more than one.

Table 5 lists the UECs and saturations of the non-appliance natural gas end uses. End uses that have experienced particularly noteworthy changes in either UEC or saturation are emphasized by shading in the corresponding cells. Space heating has shown a dramatic decline in intensity since 1990, and because the UEC data are climate corrected, the decline shown does not benefit from the fact that 2004 was warmer than 1990.[7] Given that total natural gas space heating declined (Figure 8), either a decline in intensity or saturation would be expected. For example, a strong shift to electric space heating would also help to reduce consumption of natural gas. However, the data show that the share of natural gas as the main space heating fuel has declined only slightly. Thus, real intensity declines are mostly responsible for reducing the amount of gas used for space heating. This decline in intensity is due largely to the federal standard for furnaces that went into effect in 1992 (Table 4), as well as the ongoing updates to California's building codes under Title 24.

Table 5. Unit energy consumption (kBtu per device per year) and saturation of non-appliance natural gas end uses

End Use	UEC 1990	UEC 2004	% Change, 1990–2004	Sat'n 1990 (%)	Sat'n 2004 (%)	% Change, 1990–2004
Space Heating	29,473	23,907	-18.9	79.9	78.6	-1.7
Central A/C Gas	17,907	15,543	-13.2	2.4	2.7	11.1
Cooking	5,482	4,874	-11.1	53.8	51.7	-3.9
Hot Tub Heating	16,167	16,224	-0.4	4.8	5.3	10.0
Miscellaneous	1,474	1,426	-3.3	N/A	N/A	N/A
Solar Water Htng System	3,704	3,455	-6.7	1.8	1.7	-5.3
Swimming Pool Heating	22,635	22,505	-0.6	6.5	6.5	-0.1

The other high saturation non-appliance end use is natural gas cooking equipment, which consumes about 6% of residential natural gas. While per household energy consumption has declined, this probably does not reflect a real improvement in efficiency. More likely, it is indicative of a trend toward more meals eaten out of the home and greater use of microwave

[7] The intensity of space heating should more correctly be the ratio of heating energy used per square foot of heated space, but the lack of a reliable data series on residential floor space impedes the calculation of this indicator. Because average new home sizes have consistently increased over time, the real decline in intensity has almost certainly been even greater than that shown here.

ovens. The saturation of natural gas as the main cooking fuel has declined, which may indicate that newer residences in California have a higher proportion of electric ranges and ovens.

While air conditioning is another energy-intensive end use, the saturation of natural gas-driven air conditioners is very low. The air conditioning figure shows that the intensity of air conditioning has also declined, which may reflect air conditioning performance standards and building shell improvements. Swimming pool heating uses more energy per household than air conditioning, but the saturation of natural gas swimming pool heaters has remained steady. The saturation of hot tubs using natural gas heating systems has increased some, but the overall saturation remains low.

4.4.3. Unit Energy Consumption and Saturation of Gas Appliances

Appliances fueled by natural gas are limited to two main end uses: clothes dryers and water heaters. Gas dryers only account for about 3% of total residential natural gas demand. Since many households that have natural gas for heat do not have gas dryers, the percentage of natural gas consumed in households that have gas dryers is closer to 6% to 7%. The estimated UEC of clothes dryers has, in contrast to most other end uses, actually increased since 1990. The saturation of natural gas dryers has increased slightly since 1990.

Table 6. Unit energy consumption (kBtu per appliance per year) and saturation of natural gas appliances

Appliance	UEC 1990	UEC 2004	% Change, 1990–2004	Sat'n 1990 (%)	Sat'n 2004 (%)	% Change, 1990–2004
Clothes Dryer Gas	3,271	3,473	6.2	37.0	38.4	4.0
Water Heating Gas – Total	21,100	20,286	-3.9	83.4	83.2	-0.2
Water Heating – Clothes Washer	5,915	5,683	-3.9	74.6	76.8	2.9
Water Heating – Dishwasher	5,208	4,874	-6.4	51.2	59.4	16.0

Water heating is responsible for nearly 40% of total residential natural gas demand, second only to space heating. Water heating intensity has decreased slightly since 1990. Table 6 shows not only the total energy consumption and saturation of water heaters, but also the energy consumption due to dishwashers and clothes washers in homes with natural gas water heaters. These data show that clothes washers are responsible for anywhere from a quarter to a third of natural gas consumption for water heating in most households, while dishwashers account for over a fifth (assuming there is no heated pool or hot tub). The saturation of clothes washers has not grown much, possibly because clothes washers may be nearing complete saturation of the households with gas water heating. (Note that many older or smaller apartments do not have hookups for washers and dryers; thus, the saturation of clothes washers in households with natural gas water heaters will always be lower than the saturation of natural gas water heating.) However, the saturation of dishwashers has increased appreciably since 1990, probably because newer homes and apartments almost always have dishwasher hookups installed, while many older homes and apartments do not. This may not necessarily increase residential energy consumption and

may actually save energy and water compared to washing dishes in the sink (Stamminger 2004).

4.5. Electricity Trends

4.5.1. Total Consumption and Aggregate Intensities

Total residential electricity consumption rose from 231 TBtu (67.7 billion kWh) in 1990 to 286 TBtu (83.8 billion kWh) in 2004, an increase of nearly 24%. This is a substantial increase, but only slightly more than population growth, which increased by 21%. Total estimated climate-corrected site electricity consumption by end use, with 1990 and 2004 shares, is shown in Figure 9.[8] Compared to Figure 8, it is apparent that electricity is used for a greater variety of end uses and that the total electricity use is distributed somewhat more evenly among the end uses. The graph clearly reflects the consequences of the 2001 energy crisis. Electricity consumption had been steady in the early 1990s and then began to rise significantly in the late 1990s. The electricity shortages of 2001 led to an immediate reduction of electricity consumption, but the awareness campaigns and consumer incentive programs launched during and after the crisis seem to have had some lasting effect. By 2004, total electricity consumption still had not attained the 2000 level.

Figure 9 shows that the two largest categories of consumption are refrigerators and miscellaneous end uses, which accounted for about 50% of total electricity demand in both 1990 and 2004. However, the two end uses manifest two very different patterns. Refrigerator energy consumption exhibits a slow gradual decline over time, despite the 20% growth in population. This is due to appliance standards that went into effect during this time. In the United States, refrigerators began to use more energy per refrigerator during the 1960s and 1970s because refrigerators were becoming larger and adding additional features such as auto-defrost, automatic icemakers, and through-the-door water and ice dispensing. When the first refrigerator appliance standard went into effect in California in 1977, the annual UEC began to decline. With additional standards that went into force in 1980 and 1987 in California and then federal standards that went into effect in 1990, 1993, and 2001, the UEC of new refrigerators has declined substantially (Rosenfeld 2003). The share of refrigerator consumption in the total fell from a little over 20% in 1990 to 17% in 2004.

[8] The category labeled "other end-uses" consists of end-uses for which the Energy Commission does provide disaggregated data but which were aggregated to reduce the number of end-uses shown in the graph: evaporative coolers, fans for gas furnaces, room air conditioners, solar water systems, cooking, and clothes washers.

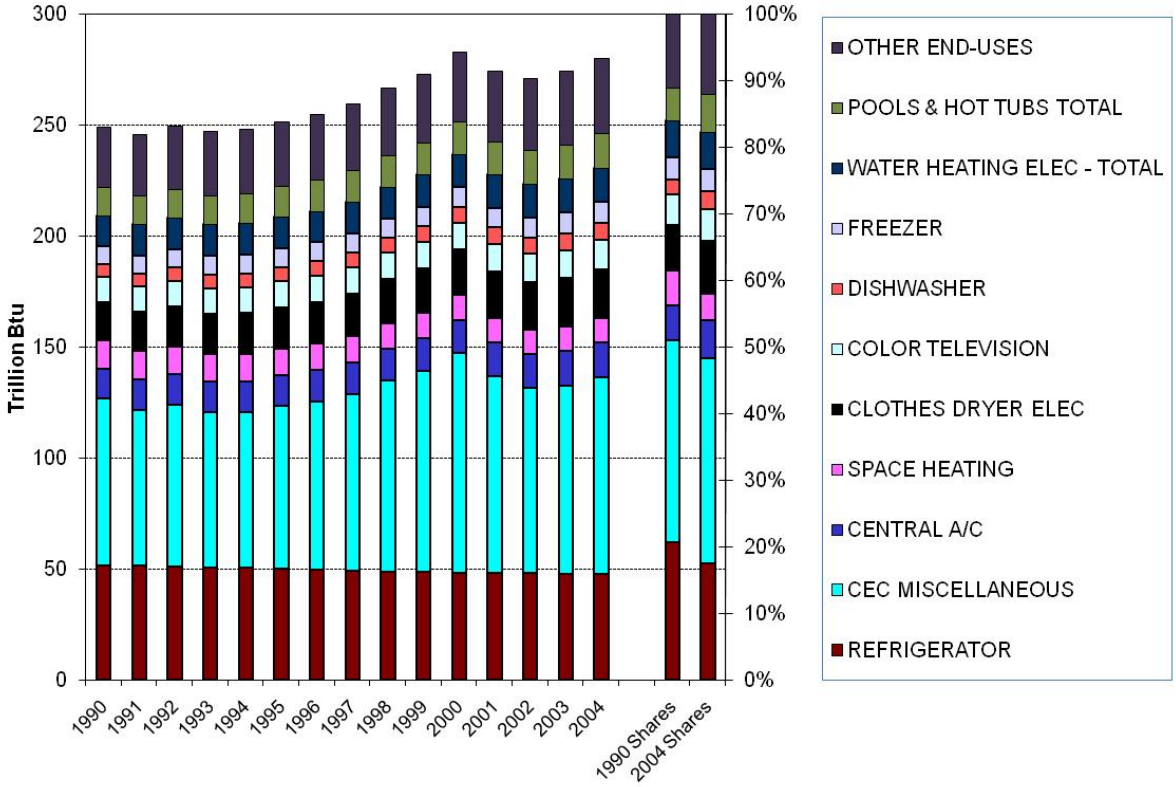

Figure 9. Total electricity consumption by end use with 1990 and 2004 shares

In contrast to the decline in energy consumption by refrigerators, miscellaneous end uses (which include lighting, small appliances, computers and other home office equipment, home electronics, and other minor uses) grew sharply in the late 1990s. Indeed, by 2000 miscellaneous energy consumption had grown over 30% above its 1990 level, rising to 35% of all electricity consumption. However, by 2004 miscellaneous uses fell to only 17% above 1990 levels and accounted for 32% of total energy use. Miscellaneous electricity consumption fell a little more than 10% between 2000 and 2001 and accounts for virtually the entire decline in total electricity consumption between those two years. This may indicate that some of end uses included in this category are luxury end uses that were more easily shed by consumers than other uses such as air conditioning and major appliances. A sharp uptick in sales of CFLs in 2001 is also likely to have contributed to sharp drop in miscellaneous consumption that occurred that year (Itron 2006).

4.5.2. Unit Energy Consumption and Saturation of Non-Appliance End Uses

Table 7 displays the UECs and saturations of the electric non-appliance end uses with key changes highlighted by shaded cells. As Figure 9 indicates, the largest single end-use category is "miscellaneous." According to the EIA's *Residential Energy Consumption Survey* (RECS), lighting accounts for about 9% of residential electricity consumption, so lighting requirements must account for a significant share of the "miscellaneous" category (EIA 2005). Because this category aggregates several different end uses, it is difficult to say exactly what the key drivers of this increase are, but growth in home electronics, computers, and other home office equipment likely accounts for most of this growth. Because the

miscellaneous category aggregates several different types of devices, a single saturation figure is not applicable. With more disaggregated data, growth in the saturation of many electronic devices would be apparent.

Table 7. Unit energy consumption (kBtu per device or household) and saturation of non-appliance electrical end uses

End Use	UEC 1990	UEC 2004	% Change, 1990–2004	Sat'n 1990 (%)	Sat'n 2004 (%)	% Change, 1990–2004
Central A/C Elec	4,535	3,704	-18.3	28.3	35.5	25.1
Room A/C	1,376	1,263	-8.2	13.5	12.2	-9.4
Evaporative Coolers	2,298	2,293	-0.2	7.0	6.5	-7.3
Space Heating	9,991	7,074	-29.2	12.6	13.1	4.5
Furnace Fan For Gas Heating	1,040	1,059	1.8	37.5	37.9	1.2
Cooking	2,418	2,527	4.5	43.4	45.6	5.1
Water Bed	4,628	4,571	-1.3	13.4	15.2	13.5
Color Television	1,135	1,108	-2.4	97.2	98.5	1.4
Miscellaneous	7,325	7,410	1.2	NA	NA	NA
Solar Water Heating System	1,484	1,472	-0.8	0.4	0.4	-12.6
Solar Water System Pump	1,496	1,432	-4.3	2.2	2.1	-6.7
Swimming Pool Heating	9,105	9,362	2.8	0.2	0.2	-7.3
Swimming Pool Pump	10,260	9,397	-8.4	9.1	10.2	11.7
Hot Tub Pump	2,758	2,774	0.6	8.3	10.7	29.4
Hot Tub Heating	1,592	1,623	2.0	2.5	3.5	39.7

Aside from "miscellaneous" end uses, central air conditioning (AC) is the largest single non-appliance end use. It accounted for a little over 5% of total electricity demand in both 1990 and 2004. However, the saturation of central AC grew significantly over this time. By 2004, over a third of all California households were equipped with central AC. If population growth occurs disproportionately in Central Valley areas, this may lead to a higher saturation of AC and will begin to increase demand for air conditioning services. Offsetting the increasing saturation of central AC was the 18% decline in its UEC. This reflects both the effect of appliance standards on the AC units themselves and the effect of building codes on improving the insulation of building shells. As Brown and Koomey (2003) point out, residential AC consumption remained relatively constant between 1975 and 1999, which is remarkable considering the growth in the housing stock and new home sizes during that time.

On a per household basis, electric space heating is a large energy consumer, using more energy than other uses except central AC and swimming pool pumps and heaters. However, the saturation of electric space heating remained quite steady. At about 13%, this saturation is much lower than the national average of 29% (EIA 2004). As with air conditioning, the UEC of space heating declined sharply. More stringent building codes also contributed to this trend, and electric furnaces were regulated by the same standards that applied to gas furnaces. Together, electricity and natural gas accounted for about 92% of the main heating fuel choice in California households. The remaining 8% are heated mostly by liquefied

petroleum gas. A small percentage of households may rely on wood or fuel oil for their main space heating fuel.

Swimming pools and hot tubs are two other large energy uses. While hot tubs and pools are found in about 10% of all California households (some homes may have both), their saturations have been growing. The share of households with a hot tub grew nearly 30% between 1990 and 2004. The UEC of swimming pool pumps has declined steadily over time, perhaps as a result of more efficient pump designs, although a decline in the average swimming pool volume would also help to reduce energy consumption for pumping. Very few swimming pools have electric heating systems, since it is expensive to meet the large heating requirements of a swimming pool with electric heating.

4.5.3. Unit Energy Consumption and Saturation of Appliances

As Figure 9 shows, refrigerators are the largest single consumer of residential electricity in California. The total energy use of refrigerators declined in large part due to the sharp drop in the UEC of refrigerators in recent years. Table 8 shows that the UEC of refrigerators fell from over 4.2 million Btu in 1990 to just over 3.5 million Btu in 2004, a decline of nearly 17%. This is due almost entirely to the enactment of two different standards during this time—one that went into effect in 1993 and a stronger standard that superseded it in 2001. These standards have had a profound effect on refrigerator efficiency, with the weighted average UEC of refrigerators shipped in the United States falling from 916 kWh/year in 1990 to 520 kWh/year by 2002 (AHAM 2003). At the same time, the percentage of homes with second refrigerators also appears to have fallen slightly. However, the saturation of freezers has increased, which partly negates the savings from the reduction in the refrigerator saturation. The UEC of freezers has also declined, since freezers are governed by the same appliance standard ruling as refrigerators.

Table 8. Unit energy consumption (kBtu per device per year) and saturation of electrical appliances

End Use	UEC 1990	UEC 2004	% Change, 1990–2004	Sat'n 1990 (%)	Sat'n 2004 (%)	% Change, 1990–2004
Refrigerator	4,245	3,529	-16.9	117.7	113.8	-3.3
Freezer	4,068	3,460	-14.9	19.4	22.3	14.9
Water Htng – Elec Total	12,328	12,011	-2.6	10.9	10.7	-1.5
Water Htng – Clothes Washer	3,472	3,391	-2.3	9.7	9.8	0.9
Water Htng – Dishwasher	3,008	2,867	-4.7	6.8	7.7	13.9
Clothes Washer – Motor	244	257	5.4	87.4	90.2	3.1
Dishwasher – Motor	923	934	1.2	60.1	69.9	16.3
Clothes Dryer Electric	3,780	3,952	4.6	43.7	47.0	7.5

Water heating also accounts for over 5% of residential electricity consumption. Table 8 shows that the saturation of electric water heaters has remained quite steady. The UEC of water heaters has declined slightly. This may be partly due to a water heater standard that went into effect in 1990. As with gas water heating, the Energy Commission estimates the amount of water heating that is attributable to the use of clothes washers and dishwashers. Having a

clothes washer in the home adds substantially to residential hot water demand, but this simply shifts demand from the services sector (laundromats). Dishwashers are also a large source of demand for hot water, but as explained above, since dishes must be washed anyway dishwashers may actually save hot water compared to hand washing. Additional rows in Table 8 provide information on the amount of electricity consumed by the motors in clothes washers and dishwashers. This indicates that most of the energy consumed by these two appliances is due to the indirect energy consumed for heating the water used by these devices. At 90% of households, clothes washers are approaching total saturation of California residences. Since many older or smaller apartments do not have hookups for washing machines, further gains in saturation will depend on turnover of the housing stock.

4.6. Primary Energy Trends

4.6.1. Fuel Share Trends

To the extent that electricity competes with natural gas for some end uses (space heating, water heating, and cooking), a trend toward greater saturation of electrical devices increases GHG emissions. Another reason to track the trends in fuel shares is that for each unit of energy used to provide the heating service, electricity is converted more efficiently to heat than natural gas or other fuels. This is because when natural gas is combusted, a large share of the heat produced escapes as waste heat in the exhaust. Thus, a trend toward a larger share of electric space heating, water heating, and cooking would give the impression that end-use intensity is going down, even though this is not really the case. In order to adjust for this factor, comparisons can also be made using units of "useful" energy.[9]

Table 9. Comparison of site energy use for water and space heating, kBtu per device per year

End Use	1990	2004
Water Heating – Gas	21,100	20,286
Water Heating – Elec	12,328	12,011
Ratio of Gas to Electric	1.71	1.69
Water Heating – Gas, Useful	13,926	13,389
Ratio of Useful Gas to Electric	1.13	1.11
Space Heating – Gas	29,473	23,907
Space Heating – Elec	9,991	7,074
Ratio of Gas to Electric	2.95	3.38
Space Heating – Gas, Useful	19,542	15,779
Ratio of Useful Gas to Electric	1.96	2.23

[9] *Useful energy* is an approximation of the amount of heat that emanates from a space heater, boiler, or furnace to a house or to water. Useful energy is equal to delivered energy in electricity, 66% of delivered energy of gases and liquids, and 55% of delivered energy in coal, wood, or other solids. It is important to differentiate between useful and delivered energy so that fuel switching for certain end-uses does not appear as an energy savings when a real decline in intensity has not occurred.

This phenomenon can be observed in data from previous tables. Table 9 shows the energy data from previous tables in order to contrast the energy consumed by gas and electric units. These values show that gas water heaters use about 70% more energy than electric water heaters. However, when the natural gas water heater energy consumption is adjusted to useful heat, the gap is much narrower, falling to about 12% higher than electric water heaters. This gap might be explained either by the roughness of the useful energy adjustment factor or by the differences in the average number of occupants per household between homes with gas water heaters and homes with electric water heaters.

The difference for space heating is much larger, with gas consumption more than 2.3 times as high as electric consumption in 2004. Even when adjusted for useful energy, site natural gas consumption for space heating is still more than twice as high per household than homes heated with electric space heating. This is probably due to two related phenomena. The first is that electric space heating is generally more common in smaller housing units, since heating with electricity is more expensive per square foot. The second is that electric space heating is more common in MFRs, which, in addition to being much smaller than SFRs on average, also have fewer exposed walls. Thus, an apartment in a multi-unit building is largely insulated from outdoor temperatures by its neighboring apartments.

Table 10. Electricity share of California residential site energy [a]

1960	1965	1970	1975	1980	1985	1990	1995	2000
11%	12%	16%	18%	22%	23%	26%	29%	32%

[a] Includes consumption of wood, which has ranged from 3% to 10% of the total.
Source: State Energy Data System (EIA 2006)

Using actual electricity consumption figures and the climate corrected natural gas figures from the Demand Model, total gas and electricity consumption increased by almost 9% between 1990 and 2004. However, with the share of electricity continuing to grow, total primary energy consumption increased over 14%. So while electricity and climate corrected natural gas consumption per capita decreased by almost 10%, primary energy per capita only decreased by about 5%. Thus, the continuing increase in the share of electricity in the residential fuel mix counters to some degree the other factors that are helping to keep energy consumption down.

5.0 Summary and Conclusions

Total service sector site energy consumption of natural gas and electricity grew from 404 TBtu in 1990 to 475 TBtu in 2003, an increase of nearly 18%. Three aggregate drivers of service sector energy consumption were examined: value added, floor area, and services employment. Floor area was found not to be a robust short-term indicator, as shown in Figure 2. Value added and employment both correlated more closely with energy consumption, and value added was selected for further analysis as an indicator. The relative increase in energy consumption was significantly less than the increase in service sector value added. Thus, the aggregate intensity ratio of site energy per real dollar of value added declined by 14%.

Structural changes in the service sector tended to increase energy consumption, particularly with the increased value added shares of restaurants and food and retail stores (see Table 2). However, the intensities of almost every subsector fell (except miscellaneous services), with the intensities of several subsectors declining by 25% or more. Without disaggregated end-use data, it is difficult to say what is responsible for the decline, but building codes must have played a consequential role in helping to reduce demand growth.

Total service sector consumption of primary energy grew faster than site energy, increasing 23%. This is due to the increasing share of electricity in the total site consumption. Excluding minor fuels, the share of electricity rose from 55% in 1990 to 61% in 2003. Due to the greater primary energy required to produce and deliver electricity, a trend toward greater electrification will increase primary energy consumption relative to site consumption.

Surprisingly, overall residential energy consumption changed relatively little between 1990 and 2004, growing only 9%. At the same time, two major drivers of energy demand grew much faster. Population increased nearly 21%, while per capita GSP increased over 25%. If residential energy consumption per unit of GSP had remained constant, total energy consumption would have increased over 50%. The declines in residential energy consumed both per capita and per GSP are impressive.

In addition to growth in population and GSP, other trends also increased demand for energy services. The increasing size of new housing units will tend to increase demand for air conditioning and space heating. Additionally, the increasing saturation of some end uses helped to drive up energy consumption. The most important end use whose saturation increased significantly is central air conditioning, which, as a large electricity consuming end use, will drive up primary energy consumption as well. Although the increases in the saturations of electric space heating and swimming pools were less pronounced, the slight increases nonetheless placed added upward pressure on demand.

Countervailing trends helped to hold total energy consumption steady. Site energy per capita fell almost 10%. This is largely due to stringent appliance energy consumption standards and building codes that went into effect prior to and during this time period. These standards and codes are particularly important since the tenant-landlord problem places the efficiency of the many end uses out of the control of the residents who use the

devices (Sathaye and Murtishaw 2004; Murtishaw and Sathaye 2007). In addition, the effect of the 2001 electricity crisis seems to have resulted in some lasting effects that reduced energy consumption through some combination of increased investments in energy-efficient devices and behavioral change.

Other factors may have also helped to limit the growth in energy consumption over this period. Given the slow growth in the saturation of most end uses, it appears that the housing stock may be nearing total saturation of some end uses. Keep in mind that for many end uses, total saturation may be well less than 100%. For example, apartments and condos (with rare exceptions) cannot have their own private swimming pools or hot tubs. Many SFRs will never have swimming pools as well, due to the space requirements and expense of installing and maintaining them. Similarly, since many apartments do not have their own washer and dryer hookups, complete saturation of these appliances has nearly been reached.

The share of electricity continued a long-term trend of accounting for an increasing share of site residential energy consumption, growing from 31% to over 35%. In California, at least in recent years, this has not been due to electrical devices capturing a greater market share for the end use where it competes with natural gas. Rather, the increasing share of electricity is due to the increased saturation of electrical end uses, principally central air conditioners. As in the service sector, the trend in increasing shares of electricity consumption has resulted in more rapid growth in primary energy than site energy, with residential primary energy increasing 14% from 1990 to 2004.

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7.0 Glossary

AARG	average annual rate of growth
AC	air conditioning
BEA	Bureau of Economic Analysis
CALEB	California Energy Balances database
CDD	cooling degree-days
CEDC	California Economic Development Department
CO_2	carbon dioxide
EIA	Energy Information Administration
GDP	gross domestic product
GHGs	greenhouse gases
GSP	gross state product
HH	household
HDD	heating degree-days
kg	kilograms
kWh	Kilowatt-hour
LPG	liquefied petroleum gas
MFR	multifamily residence
NAICS	North American Industrial Classification System
RECS	Residential Energy Consumption Survey
SEDS	State Energy Data System
SFR	single family residence
SIC	Standard Industrial Classification
TBtu	Trillion Btu
TCU	Transportation, Communications, and Utilities
TWh	terawatt-hour
UEC	unit energy consumption