LBL-29749
UC-350

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Analysis of Energy Use in Building Services of the Industrial Sector in California: A Literature Review and a Preliminary Characterization

H. Akbari, T. Borgers, A. Gadgil, and O. Sezgen

April 1991

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-29749

Analysis of Energy Use in Building Services of the Industrial Sector in California: A Literature Review and a Preliminary Characterization

April 1991

Prepared by

H. Akbari, T. Borgers*, A. Gadgil, O. Sezgen
Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

This study was jointly sponsored by the University-wide Energy Research Group (UERG) under a grant to the Center for Environmental Design Research at the University of California, Berkeley and by the California Institute for Energy Efficiency (CIEE) (Award No. EXP-90-09) through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

* On sabbatical leave from California State University (Humboldt) at Lawrence Berkeley Laboratory, 1987 - 1988.

ABSTRACT

Energy use patterns in many of California's fastest-growing industries are not typical of those in the mix of industries elsewhere in the U.S. Many California firms operate small and medium-sized facilities, often in buildings used simultaneously or interchangeably for commercial (office, retail, warehouse) and industrial activities. In these industrial subsectors, the energy required for "building services" to provide occupant comfort and necessities (lighting, HVAC, office equipment, computers, etc.) may be at least as important as the more familiar process energy requirements--especially for electricity and on-peak demand.

In this report, published or unpublished information on energy use for building services in the industrial sector have been compiled and analyzed. Seven different sources of information and data relevant to California have been identified. Most of these are studies and/or projects sponsored by the Department of Energy, the California Energy Commission, and local utilities. The objectives of these studies were diverse: most focused on industrial energy use in general, and, in one case, the objective was to analyze energy use in commercial buildings. Only one of these studies focused directly on non-process energy use in industrial buildings.

Comparison of the findings of these studies and/or databases is difficult because of the varying objectives of the studies; the reported data format; the way data are aggregated in each study; the varying coverage of industries in each study; and the problem of comparing data from different time periods. The most relevant information for California comes from two studies using data from U.S. Census Bureau Census of Manufacturers and on-site audit information collected in Northern and Central California during 1981-1984. Although all studies addressed different objectives, focusing on different areas, time periods, and industries, they all pointed to the importance of non-process energy use in industry as an area for potential conservation. The situation is even more promising for California where industries like instrumentation and computer manufacturing are concentrated; these industries consume most energy for air conditioning and lighting.

One study approximated building non-process energy use to be 15% of total industrial energy use for the U.S.; of that, 84% was used for space heating, 8% for air conditioning, and 8% for lighting. Another study estimated a similar overall percentage (15.3%) for industrial non-process energy use, but 17% of that went for lighting, 31% for air-conditioning, and 52% for space heating. Also, a national study for the manufacturing sector estimated that 17% of purchased energy used in 1972 in that sector went for space conditioning and lighting.

Our analysis of Northern California data for five selected industries shows that the contribution of total electricity consumption for lighting ranges from 9.5% in frozen fruits to 29.1% in instruments; for air-conditioning, it ranges from nonexistent in frozen fruits to 35% in instrument manufacturing. None of the five industries selected had significant electrical space heating. Gas space heating ranges from 5% in motor vehicles facilities to more than 58% in the instrument manufacturing industry.

Acknowledgements

This study was co-sponsored by the University-Wide Energy Group through a grant to the Center for Environmental Design Research at the University of California, Berkeley and by the California Institute for Energy Efficiency (Award No. EXP-90-09).

We are indebted to Mrs. Gloria Nugent and Mr. William Idzerda, both of PG&E, for allowing us access to the BAH report[2], for granting permission to examine it, and also to use the PG&E EUA database.

Table of Contents

List of Figures

List of Tables

I. INTRODUCTION

Industry uses approximately 35% of the total energy consumed in the United States. Of this 35%, manufacturing uses about 78%, mining 10%, and agriculture and construction each 6%. Historically, heavy industry (e.g., iron and steel, oil refining, and heavy equipment manufacturing) has dominated, and it continues to dominate industrial energy use in some parts of the country even today. Industries that consume most energy nationwide are, in order, (1) chemicals, (2) primary metals, (3) petroleum refining, (4) paper, and (5) stone, clay, and glass. These five industries accounted for about 80% of the national energy use for manufacturing in 1984. [1]

California industry includes some of major energy users, such as chemicals, petroleum refining, paper, and glass, but more common, relative to the national mix of industries, are electronics, instruments, aircraft, light assembly, and food. Major reasons for the difference between California's mix of industries and the nation's are: stricter environmental regulations that deter the heavy smokestack industries; and the absence of nearby supplies of high quality coal (such as Appalachian deposits) for ore reduction, and/or cheap hydroelectric power for electrolytic processes (like that available in the Pacific Northwest). Of course, other economical and non-economical factors can be equally influential in the final mix of industries in the state, but they are not the focus of our report.

The concentration of high technology in California is largely responsible for its different and continually changing industrial mix. Workplaces that produce high-technology products routinely have a high degree of indoor thermal comfort and a great deal of task lighting, especially where dexterity and attention to fine detail are required. Furthermore, even in "mature" industrial categories the proportions of fuel types purchased continue to change. For example, the percentage of total purchased electrical energy has increased in some industries despite increases in the price of electricity relative to gas.

Major industries that have grown recently and purchased increased amounts of energy in California include oil extraction, electronics and electronic equipment, machinery, and fabricated metal products [2].

The California Energy Commission (CEC) assesses and forecasts future energy demands in the state. Reliable data are needed for both forecasting the dynamics of growth and decline industry by industry, and also analyzing energy requirements by each fuel type. Some data currently used by the CEC are examined in this study.

Efforts to quantify and characterize the use of non-process energy in U.S. industry have received low priority in the past from governmental agencies, utilities, and industry managers. A possible reason for this inattention is the focus on increasing the efficiency of energy use in the process sectors of plants. This focus is easily appreciated when the process itself consumes an overwhelming portion of the purchased energy. Heavy industries (such as smelting, oil refining, glass and cement) are intense users of process energy. However, a rapidly growing number of industries, especially in the high technology sector prevalent in California, use a significant portion of purchased energy to heat, cool, light, and ventilate the workplace. In some instances, environmental conditions in process areas are stringently defined and controlled for humidity, temperature, and particulates, which adds to energy use for building services. This high-technology industrial group is expected to become increasingly important in the future.

Between these extremes is a spectrum of industries, which, to a greater or lesser extent, use energy to light and condition the workplace and which the process itself contributes significantly to heating or cooling requirements.

This study attempts to characterize non-process building energy and power use in California's industrial sectors and to identify relevant conservation opportunities. Our efforts centered on acquiring published and unpublished energy end-use data from industrial users, public domain data bases, utilities, consultants, and journals. Several earlier studies have noted (and we agree) that reliable data are scant. There are many reasons for this:

- Smaller establishments do not document and disaggregate their energy end-uses. Small firms find it uneconomical to allocate personnel and material to meter or otherwise acquire and process these data.
- Many industrial users believe non-process energy use is negligible and are not interested in expending the effort to characterize these uses and explore conservation opportunities.
- Some industries, such as segments of the food processing industry, are seasonal. Capital investment to conserve or reduce non-process energy may not be the best use of their resources.
- Perhaps the most often quoted reason for the lack of data from larger enterprises is that energy end-use data would reveal proprietary processes to their competition.

In a report by the Electric Power Research Institute (EPRI) [3], Jones and Limaye observe that "There is considerable reluctance by utilities to spend resources collecting data for an as yet undefined econometric model. The risks of collecting too little or useless data are great." The type of data required to develop and support energy use models would include energy use characteristics of industrial processes and production techniques. The utility industry has little incentive to address industrial energy use and conservation possibilities because the system load factors for many utilities have been declining in recent years. However, in California, the legislature has established a separate regulatory agency, the California Energy Commission (CEC), charged with determining the need for new power generation facilities in the state. This agency requires utilities to submit descriptive data on all classes of customers. The first attempt in 1984 to gather these data was not satisfactory. Some of the problems encountered in the attempts to assemble the required data were:

- Individual customers generally do not have information on their energy end-use patterns.
- In most cases, detailed process information is considered proprietary.
- Customers do not take the time to complete the surveys.
- Industrial processes can be complex, which hindered information gathering.
- Estimation of end use is not simple and straightforward because equipment power requirements vary considerably from full load to idle.
- Complications arise where plants produce multiple products which may represent multiple Standard Industrial Classification (SIC) codes, which makes assigning energy end use by SIC code difficult.
- Defense-related industries cannot divulge information on their facilities.
- After customers complete time-consuming surveys, a substantial amount of analysis and estimation is required to develop end-use data.

Several electric utilities were surveyed to determine their experience with collecting industrial end-use data. Bonneville Power Administration (BPA) and North Carolina Alternative Energy Corporation (NCAEC), in a contract awarded to Synergic Resources Corp. [4], have attempted to develop end-use data bases using survey data and secondary data bases. A number of important lessons were learned in these attempts. Utilities learned that, in order to obtain data, mail surveys have to be followed with phone calls or on-site surveys by skilled and knowledgeable interviewers. In 1980, EPRI funded a review of industrial energy end-use data bases that covered about 30 studies of industrial energy end use and 11 industrial end-use data bases. The reviewers concluded that there are many different data bases on industrial energy end use, but data lack consistency. The main weaknesses of the existing data bases are:

- They address primarily thermal energy end uses. The quality and quantity of information on electricity end uses are limited.
- Most data bases that present end-use information by quality and quantity represent only hypothetical or reference plants, rather than actual plants.
- There is significant variation in the data reported in different data bases. This may represent different use patterns across the country, but we have found no attempts to provide statistical measures of the variation.
- Even though significant resources have been expended on data base development, little effort seems to have been made to verify and validate data.
- Information gathered in one part of the country may or may not apply to other particular geographic areas; this needs to be ascertained.

According to utility representatives, the utilities most successful in obtaining information used interviewers who had earned the trust of customer personnel. A recommended approach in data base development is to provide the interviewer with standardized flow diagrams for each 4-digit SIC, identifying the minimum parameters whose values must be recorded, along with "default values" to be used only when on-site data collection is difficult. The interviewer must also have adequate background information on each industry and production process, so that he or she can modify the process diagram on-site and gather, or closely estimate, pertinent data for analysis of the facility. Interviewers must be highly skilled and knowledgeable in the industrial process being examined.

The best way to acquire these data is by measurement although data obtained in this manner would be site-specific and costly. Even within 4-digit SIC codes, investigators have found wide variations of end use in building services.

II. DATA EXAMINED

For this report we examined a variety of data sources. We describe several below. The sources include national data as well as California-specific and regional data. The data bases to which we give the most attention are:

1. Nonresidential Buildings Energy Consumption Survey, (NBECS) [5]
2. Industrial Energy Use Data Book [6]
3. Industrial Buildings Energy Use, (a report by Hagler, Bailly and Company (HBC)) [7]
4. A Characterization of Energy Use in Selected California Industries, (a report for the CEC by Energy and Resource Consultants, Inc (ERC)) [8]
5. Pacific Gas and Electric Company (PG&E) industrial audits [9],
6. Industrial Sector Market Study of PG&E customers, (a report prepared by Booz, Allen and Hamilton, Inc. (BAH)) [2],
7. Energy Conserved and Costs Saved by Small and Medium-size Manufacturers, Energy Analysis and Diagnostics Centers (EADC) Program Period of 1984-85 [10], and
8 Documented data from facilities winning ASHRAE awards for energy efficiency.

Summaries of these and other data sources follow. Some characteristics of these sources are summarized in Table 1. An attempt to compare the data available from different sources is made in Figure 1. Comparison makes sense if energy use intensities are known. End-use data are available in the HBC and ERC studies and the PG&E audits. Unfortunately facility areas are available only in the PG&E audits. We estimated the energy use intensities for end uses for HBC and ERC data by reproportioning the total consumption intensities from PG&E data based on the percentage end use figures supplied by HBC and ERG for consumption. It should be noted that ours is a gross approximation because : 1) what these sources cover is very different and 2) the way the industries are classified are also very different.

II.1. Non-Residential Building Energy Consumption Survey (NBECS)

The Nonresidential Building Energy Consumption Survey(NBECS)[5] was conducted for the U. S. Department of Energy. The study was designed to characterize energy use in commercial buildings. By mistake, 11% (620) of the surveyed buildings were industrial. These data were examined and manipulated without much success in an attempt to draw conclusions regarding end-use characteristics of industrial buildings. The details of this analysis are given in Appendix 1.

The only information about locations of the buildings was census region numbers. Although precise locations were not needed for this study, knowledge of climate conditions could help us understand energy use. Therefore, each building's location was inferred using annual heating and cooling days and rate figures given for electricity and gas. Based on this approach, we chose 39 buildings as probably being in California.

In this survey, a further complication was that industries were not classified by SIC; thus, there is ambiguity about the details of industrial activity in the buildings. Generally, much of the information that could be useful for discovering energy end uses is missing in this survey.

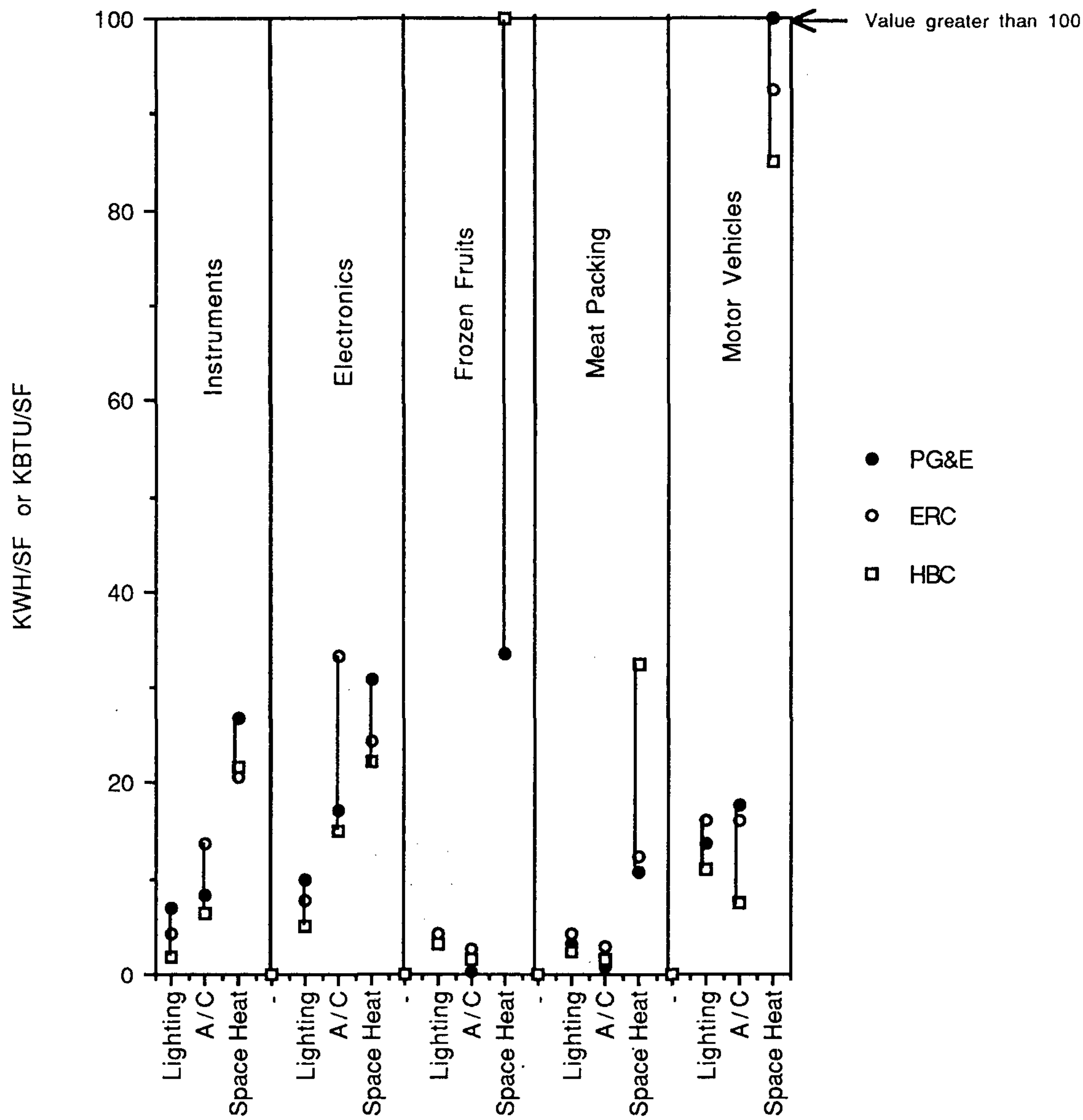
Table 1
Characteristics of Data Sources

Study	Organizations Involved	Objective of Study	Scope of Data	Source of Data	Year of Data	Non-Process End-Use Data	Structure of Data	Associated Data Base
Non-residential Building Energy Consumption Survey (NBECS) [5]	DOE	Analysis of energy use in commercial buildings	Nationwide data for non-residential buildings. 620 industrial buildings included by mistake. 39 estimated to be in California	Questionnaires.	1979	None	Not classified using SIC	
Hagler, Bailly & Company (HBC) [7]	HBC for DOE	Analysis of non-process energy use in industry	Nationwide	Discussions with 37 energy managers. Detailed audits since 1980. Literature Surveys. Correlations with Dunn & Bradstreet data base [13]	1980-1987	Space heating. Vent, A/C. Lighting	SIC form	Dunn and Bradstreet [13]. (Nationwide) HBC Database (limited) Nationwide.
Energy Analysis & Diagnostic Centers (EADC) [10]	University City Science Center for DOE	To test actual impact of conservation measures for industry	12 states (not CA).296 small-medium companies	Reports from retrofitted facilities.	1984-1985	None	SIC form	
Energy & Resources Consultants (ERC) [8]	ERC for CEC	Trend analysis of industrial energy use	California. Covers ~70% of industrial energy use. Covers only 45% of energy use in food industries.	Mostly from U.S. Census Bureau, Census of Manufacturers	Mostly 1977	Space heating. Vent,A/C. Lighting.	Based on SIC form, aggregated into supergroups	ERC data base. (California)

Table 1 (contd.)
Characteristics of Data Sources

Study	Organizations Involved	Objective of Study	Scope of Data	Source of Data	Year of Data	Non-Process End-Use Data	Structure of Data	Associated Data Base
Booz,Allen & Hamilton (BAH) [2]	BAH for PG&E	Trend analysis of industrial energy use.	PG&E area. 25-98% of electricity, 16-57% of gas purchases of several SICs.	Audits and questionnaires. (PG&E EUA)	1981-1984	Space heating. Vent,A/C. Lighting.	SIC form.	PG&E EUA data base. (PG&E service area)
Industrial Energy Use Data Book (IEUDB)[6]	Oak Ridge Associated Universities	Database for industrial energy use in general	Nationwide	Census of Manufactures. Census of Mineral Industries. Census of Construction Industries. Mineral Industry Surveys. Mineral Year Book, etc.	1975-1980	Only electricity for VAC and lighting together for some cases	SIC form	IEUDB [6] Nationwide

Figure 1
Electricity and Gas Use Intensities for Five Selected Industries



Nonetheless, we attempted to discover pertinent information on non-process energy end use in the 39 industrial buildings identified earlier as probably located in California. Electricity and gas consumption were examined to see if there were correlations between use, number of workers, hours of operation, unit costs, and other factors that can be derived from the data available. However, no pattern is identifiable, and there are huge variations in ratios that would ordinarily be expected to lie in a narrow range of values for a given type of industry. Even for buildings within the same industrial group and with similar heating and cooling degree days, we cannot discover such a pattern.

The widely spread values indicate several possibilities: 1) the data may be flawed, 2) the technology used in process or building services varies widely within the same industry, 3) the data base does not delineate the industrial processes in adequate detail to justify or explain what may be appropriate differences.

The reported data are inadequate for estimating the power used for cooling. The same applies for the data that could correlate consumption of natural gas, fuel oil, and liquid gas with heating degree days and percent of the facility which is heated.

II.2. Hagler, Bailly & Co.

In a report to DOE, Hagler, Bailly & CO. (HBC) [7] studies non-process energy use in industrial buildings nationwide. The information presented in the report is based on literature surveys, discussions with 37 experts in the field, and detailed audits performed by HBC since 1980. A summary of this report and how it is used for our study is given in Appendix 2.

Based on the assumption that the majority of medium and large industrial facilities use boilers and/or furnaces that burn fossil fuels, estimates of space heating were based on total fossil fuel use. Estimates of ventilation, cooling and lighting are based on electricity consumption. For estimates of space heating, we correlated heating degree days, number of production employees, and electric-to-fossil ratio with the 1984 reported space heating consumption tabulated in the Dun & Bradstreet Major Industrial Plant Database [14].[1] Ventilating and air-conditioning (VAC) estimates were handled the same way.

We used HBC findings to estimate the average percentage of total fuel consumption attributed to heating and the average percentage of total electricity consumption attributed to cooling in California. According to these estimates, California use differs little from the national averages. The percentage contribution of VAC to total electricity use differs significantly from the space heating contribution to total fuel use because not all industrial facilities require air conditioning, and the total plant consumption of electrical energy can be high; thus, the percentage contribution of VAC to total electrical demand can be small.

Apart from information characterizing non-process energy use in industrial facilities, the HBC report presents a lot of information on trends in retrofitting these facilities for energy conservation and identification of research and development (R&D) opportunities in energy conservation for industrial buildings.

HBC concludes that industrial building non-process energy use is approximately 15% of total industrial energy use. Approximately 84% of the non-process energy used by industrial

[1] DBMIPD details the process and plant energy use of over 21,000 industrial facilities nationwide, accounting for an estimated 90% of total U.S. industrial energy use.

buildings nationally was for space heating. Air conditioning/ventilation and lighting divide the rest equally. Their discussions with industry and research organizations indicate that 20% of non-process energy could be conserved.

II.3. Energy Analysis and Diagnostic Centers (EADC)

This report provides a summary of energy conserved and costs saved by small and medium-size manufacturers during the 1984-85 EADC program period [10]. Ten EADC centers recommended 2,168 energy conservation measures over a 12-month period to 296 small and medium-sized manufacturers located in 24 states other than California. Recommendations were presented to manufacturers individually after on-site analyses of their plants. These companies, representing 18 different industries, showed potential savings of about 10% of the plants' total energy costs and about 11.5% of total energy use. Approximately 75% of the identified energy conservation potential was in process use, which accounted for about 66% of the identified actual dollar savings 1984-1985.

The major recommended energy conservation measures for buildings and grounds amounted to about 20% of the energy conservation potential and 27% of the cost savings potential. Implemented conservation measures in buildings and grounds amounted to 26% of the energy conserved and 31% of the cost saved, indicating that management is more likely to implement equipment and procedure changes that do not directly involve the plant process itself. The conservation measures in buildings and grounds showed the largest dollar savings in both recommended and implemented categories. Space heating and cooling conservation measures were implemented almost as often as lighting recommendations and saved about 1.8 times as much money.

In Appendix 3, statistics for conservation measures most frequently implemented and the top dollar-saving measures that may apply to building services are given together with a more detailed review of the EADC report. We noted that installing timers and/or thermostats for heating and air conditioning resulted in 12.4% of all implemented conservation savings.

If these findings in states outside California are any guide to conditions of industrial facilities within California, a significant amount of energy use could be eliminated cost-effectively by conservation measures in building services. Recommended conservation measures for the buildings in the study would reduce energy use by about 11.5% and reduce costs by 10.0% . Implemented conservation measures are estimated to have resulted in 5.5% reduction in energy use and 5.3% reduction in energy costs. It is not easy to predict the degree to which a similar program in California would be successful, compared to the other 24 states. First, it is unknown to what extent the utilities that serve these regions engaged in conservation efforts comparable to those in California. Second, because of differences between the industrial mix in California and that in the eastern U.S., conservation potentials for California industries may be greater in the building services category.

II.4. Energy and Resources Consultants, Inc. (ERC)

A study performed by Energy and Resources Consultants, Inc. (ERC) for the California Energy Commission and released in 1983 identifies many of the industrial categories that are expected to use appreciable amounts of energy for building services [8]. The ERC report is intended to be a tool for forecasting the energy demand by industry. The details of this report are summarized in Appendix 4.

Many industries covered by this report do not consume much energy statewide. Most of the major energy using industries, which usually show comparatively negligible non-process use, have been addressed in other work by the CEC. The two major users covered by this report are the chemical and glass industries. Most of the data cited were originally obtained from the U. S. Census Bureau Census of Manufacturers (1977); it is therefore dated by more than a decade.

Instead of analysis strictly by SIC, ERC aggregated the SICs of interest into 38 groups on the basis of similar perceived patterns of energy use, then further combined them into eight major classes or "supergroups" which were labeled: 1) chemicals, 2) glass, 3) mineral products, 4) metals, 5) materials processing and conversion, 6) electronics, 7) general fabrication and assembly, and 8) food and kindred.

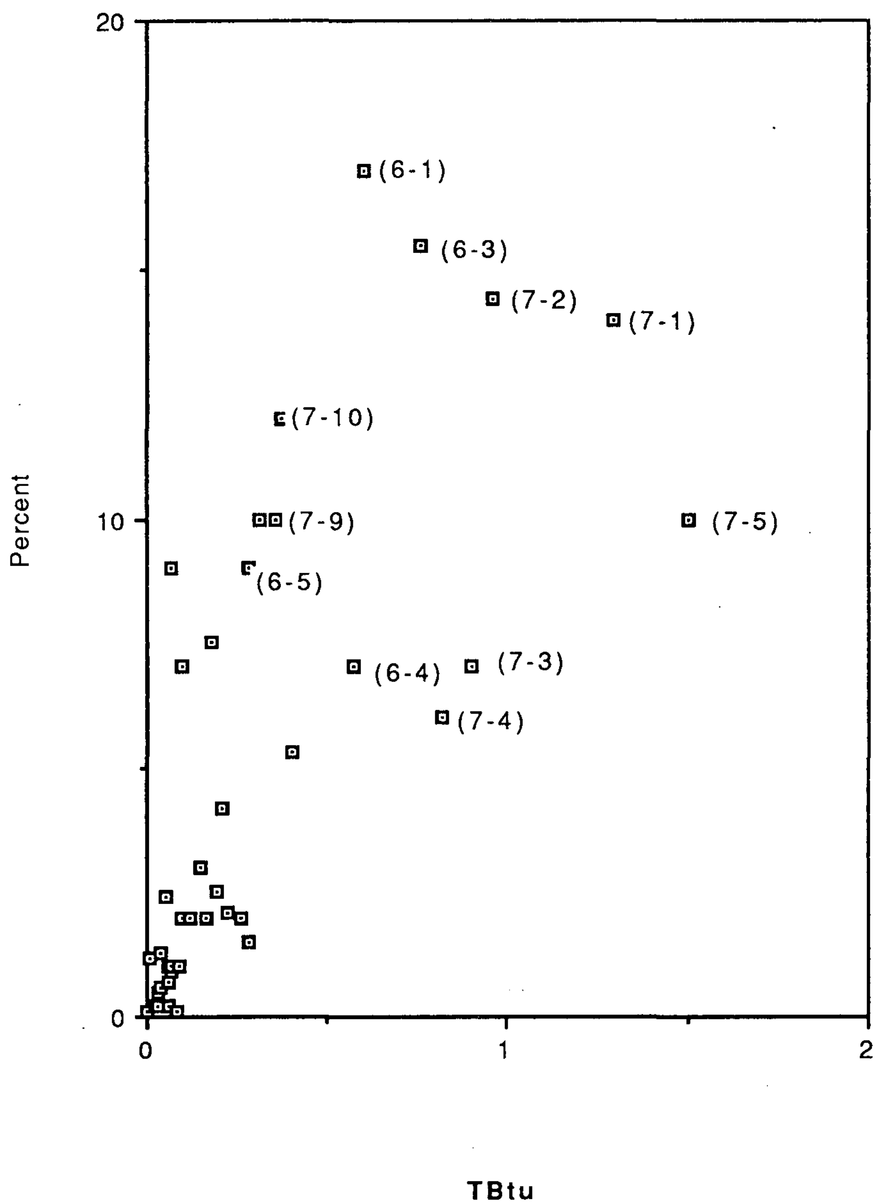
The annual industrial site purchased energy use in California, surveyed by ERC, is 448.3 trillion Btu (TBtu). The total California industrial energy use in 1976, according to the Industrial Energy Use Data Book was 624.7 TBtu; thus, this survey covers approximately 70% of California industrial use. The important sectors omitted from the California food industry in the ERC survey include fruits, vegetables, and frozen specialties. The Industrial Use Data Book (1977) shows that the California food industry purchased 98.5 TBtu; thus, the above coverage by ERC accounts for only about 45% of the energy use by this industrial sector.

ERC has provided energy end-use estimates in which the categories of lighting, air conditioning and ventilation, and space heating are the non-process or service uses of interest to this study. Also presented from the ERC study is the mix of purchased source fuel for each group.

ERC data do not include any information concerning facility sizes, construction, or number of facilities; thus, no Energy Use Intensity (EUI) determinations or efficiency estimates are possible. Information that may point toward conservation potentials is indicated in plots of percent of total purchased energy used for lighting, A/C ventilation, and space heating versus the quantity of purchased energy for those purposes. This represents an effort to highlight industries that have important non-process loads and at the same time display the importance relative to other industries for the same category of end use.

The industries that may benefit most from conservation measures for non-process energy use can be seen from Figure 2, which shows percent of purchased energy used for lighting versus amount of energy used for lighting. Industry categories that appear to use a high percentage of energy for lighting and/or a large quantity of lighting energy are (7-5) light machinery and similar, (7-1) aircraft, (7-2) spacecraft, (6-3) communications equipment, (7-4) heavy machinery and manufacturing, (7-3) motor vehicles and related products, (6-4) electronic components, (7-10) apparel, (7-9) furniture, (6-5) electronic instruments, (6-1) computer and office machines.

Figure 2
Percent of Total Purchased Energy which is Used for Lighting versus Quantity of Energy Used for Lighting



Most air conditioning and ventilation is electrical. Figure 3 shows percent of purchased energy versus the quantity of energy used for air conditioning and ventilation. Several industries appear to be strong candidates for conservation. ERC data for industry categories (6-4) electronic components, (6-3) communications equipment, and (6-1) computers and office machines, indicate that 30% or more of purchased energy is used for A/C ventilation. ERC assumed that no gas or other source fuel was used for air conditioning even though the technology (e.g., gas-driven air conditioning) has been commercially marketed for at least 15 years. Current data would undoubtedly reflect some adoption of this technology.

Because the cost of an electrical Btu is roughly 4 times that of a source fuel Btu, industrial categories that use large amounts of purchased energy for lighting and air conditioning may, after conservation potential studies, realize the most rapid payback from effective conservation measures.

In Figure 4, industries that use large percentages of purchased energy for space heating are (7-5) light machinery, (7-3) motor vehicles, (6-4) electronic components, (6-3) communications equipment, (6-5) electronic instruments, (7-10) apparel, (7-9) furniture, (7-8) optical and medical instruments, (6-2) home electronics, and (7-13) wood containers; all of these use approximately 30% of purchased energy to heat their facilities.

Figure 5 shows industries that use 30% or more of purchased energy for lighting and air conditioning/ventilation. They are (6-5) electronic instruments, (7-8) optical and medical instruments, (7-10) apparel, (7-2) spacecraft, (6-4) electronic components, (6-3) communications equipment, and (6-1) computers and office equipment. We can see from the figure that in some industries approximately 50% of the total purchased energy goes toward lighting and air conditioning/ventilation. These industries are among those expected to grow the most rapidly in California in the immediate future.

According to ERC estimated data for the surveyed California industries overall, 2.7% or 12.0 TBtu purchased energy is used for lighting, 4.7% or 21.0 TBtu is used for air conditioning and ventilation, and 7.9% or 35.7 TBtu is used for space heating. Hence, of the total nonprocess energy use (15.3% of total energy use) in 1977, 17.0% went for lighting, 31.0% was used for air conditioning and ventilation, and 52% was used for space heating. These proportions have undoubtedly changed during the past decade because of dynamic changes in the mix of California industries.

II.5. Booz, Allen and Hamilton, Inc. (BAH)

We examined the fragmentary regional data available from an analysis done by Booz, Allen and Hamilton, Inc. (BAH) of Pacific Gas and Electric's (PG&E) industrial audits. This analysis is published in a report, [2], by BAH to PG&E, dated February 26, 1986. Although a brief summary of the BAH report is given here, a more detailed analysis of this work can be found in Appendix 5. The BAH report emphasizes analysis of electricity and gas sales trends. Energy use trends in several industries are summarized based on the data for 1981 - 1984.

Figure 3
Percent of Total Purchased Energy which is Used for A/C and Ventilation versus Quantity of Energy Used for A/C and Ventilation

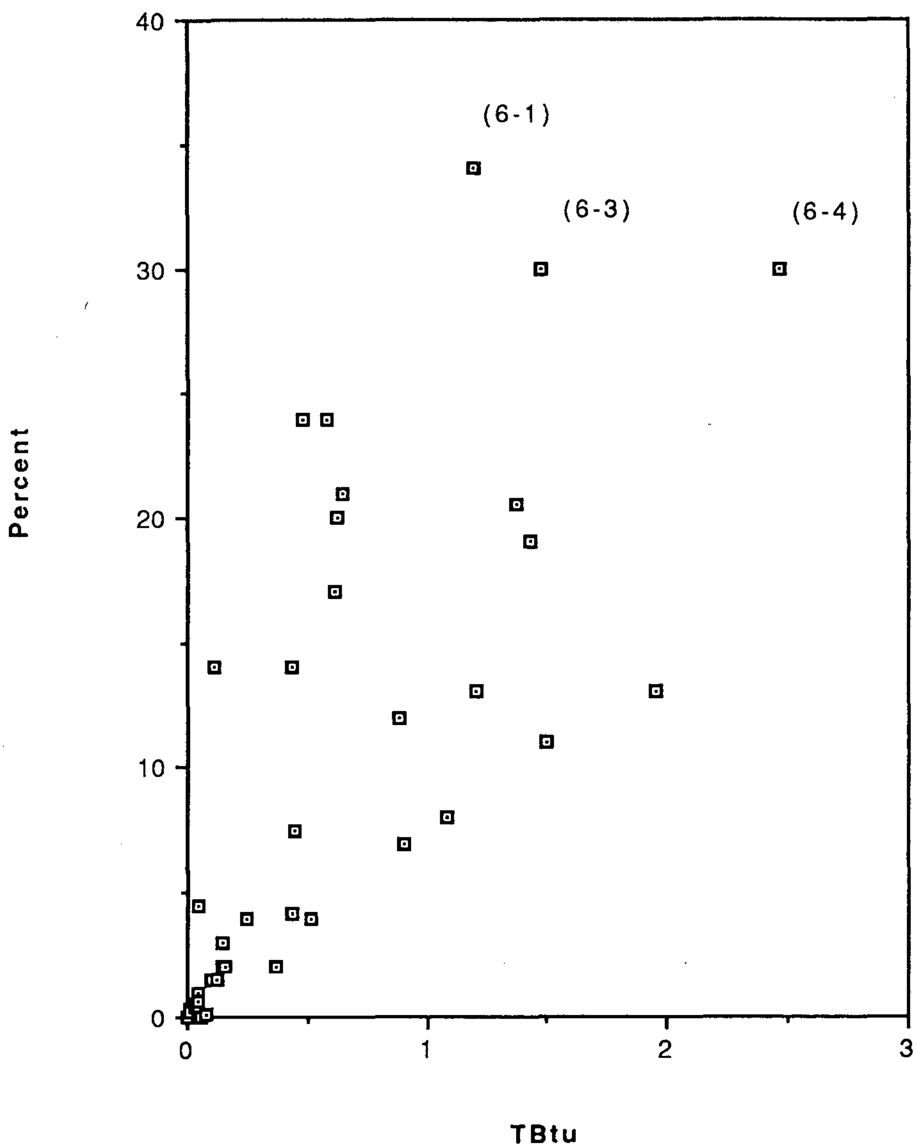


Figure 4
Percent of Total Purchased Energy which is Used for Space Heating versus Quantity of Energy Used for Space Heating

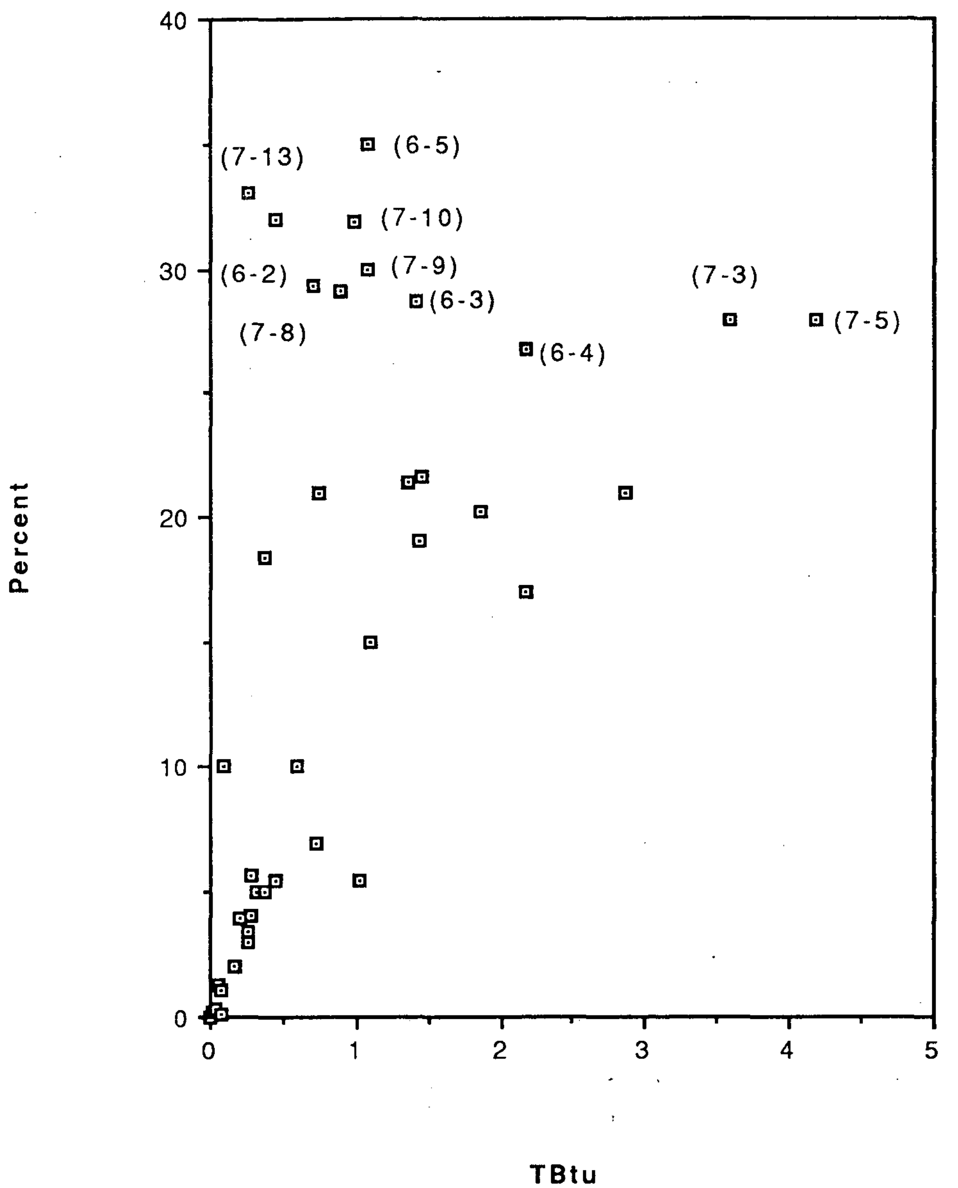
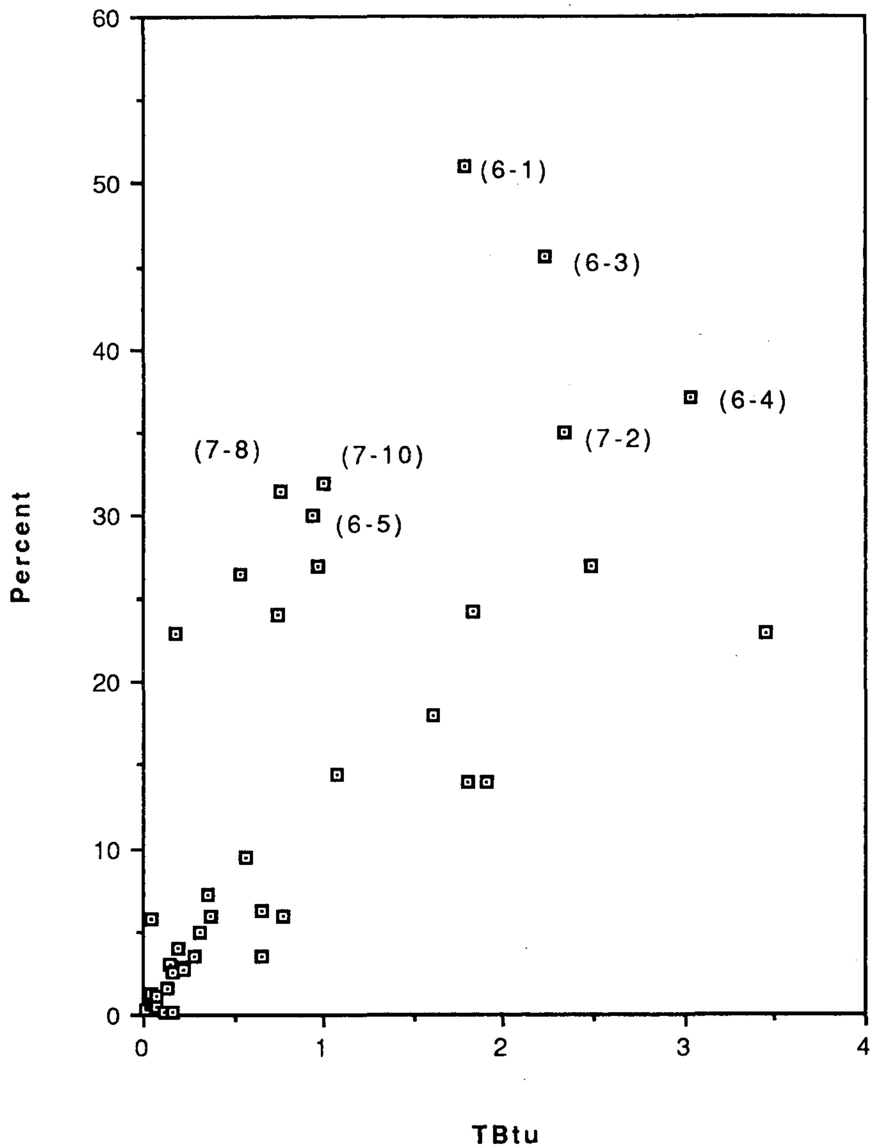


Figure 5
Percent of Total Purchased Energy which is Used for Lighting , A/C and Ventilation versus Purchased Electrical Energy for same purposes



According to this study, space cooling is the largest end use of energy for the semiconductor industry, SIC 3674 and the computer industry, SIC 3573. For the semiconductor industry, SIC 3674, energy use by end use breaks down as: air conditioning 39.2%, lighting 12.4%, motors 13.0%, hot water 0.1%, miscellaneous (possibly computers or other office equipment) 9.1%, process heat 25.7%, and space heating 0.5% of the total energy purchased. For the computer industry, SIC 3573, the breakdown is: air conditioning 36.4%, lighting 26.7%, motors 16.4%, hot water 0.3%, miscellaneous 12.2%, process heat 7.3%, space heat 0.3%, and refrigeration 0.4%.

The above figures are averages. If a site by site analysis is undertaken, one finds a large variation in the fractions of the total electrical consumption used for air conditioning even within the same 4-digit SIC code. The PG&E data base shows, for example, that, in the semiconductor industry, SIC 3674, use of electricity for air conditioning as a percentage of total kWhs purchased varies from 5% to nearly 70%; these figures for the computer industry, SIC 3573, vary from negligible to more than 70%. To establish the validity of the wide variations indicated above for air conditioning, climate factors must be examined. In projecting energy use for future growth, more detailed information must be gathered to construct reliable demand forecasting models; for example, locating a plant of the same 4-digit category a few miles closer to or farther from the coast may dramatically affect space conditioning requirements.

BAH also makes several suggestions concerning the PG&E industrial database; these suggestions are summarized in Appendix 5.

II.6. Industrial Energy Use Data Book (IEUDB)

This massive compendium of data on energy use in industry was prepared by Oak Ridge Associated Universities in 1980[6]. The stated primary objective of this work was to gather, compile, and validate information on industrial energy use. The purpose was to help formulate public and private policies regarding energy conservation, allocation, and production. The book relies on a large number of data sources: Census of Manufacturers and Annual Survey of Manufacturers, Census of Mineral Industries, and Census of Construction Industries, all from the Department of Commerce; Mineral Industry Surveys/Energy Data reports, and the Minerals Yearbook from the Bureau of Mines/Department of Energy, Major Fuel Burning Installation Survey, Energy Consumption Data Base, Monthly Energy Reviews, and Voluntary Business Energy Conservation Program from Federal Energy Administration/Department of Energy, data from trade associations, such as the American Gas Association, studies on major industrial processes from Drexel University, and the Capital Stock Data Base, developed by Jack Faucett Inc. for the Bureau of Labor Statistics. The book's authors have assessed conflicting data and provided what they consider to be the more realistic (and reasonable) data wherever conflicting data were found (they also provide reasons for choosing one data source over another when they have made a choice).

The book was published in 1980, and some of the data in it are as old as 1975. These data are in some ways outdated; the structure of the industries has changed in some instances as a result of evolving technologies and product changes, and also partly because of energy conservation. We can also expect that some of the energy disaggregation will have changed. Finally, differences in fuel prices have also probably led to gradual fuel switches in the industries.

The book is divided into three major sections. The first section provides information on data sources, methods of data collection, limitations of data, and general economic significance of industrial energy use and its relationship to major indices in the economy; in addition, it gives historical details on supply, demand, and imports, and an accounting of private investment and public policy on industrial energy. The second section, of interest to us, details energy use in agriculture, mining, construction, and the 10 most energy intensive industrial sectors in the U.S. economy. As we discussed earlier in this report, the industrial sectors whose energy use is important for California are significantly different from those for the U.S. as a whole. The industries covered in detail in the IEUDB are: food (SIC 20), textiles (SIC 22), paper and allied products (SIC 26), chemicals and allied products (SIC 28), petroleum refining (SIC 29), stone, clay and glass products (SIC 32), primary metals (SIC 33), fabricated metal products (SIC 34), non-electrical machinery (SIC 35), and transportation equipment (SIC 37). Of these, the ones of interest to California are the refining, stone-clay-glass, food, plastics (under SIC 28 and 30), and computing equipment and electronics (under SIC 35 and 36) industries. Only the relevant data from the IEUDB for industrial buildings energy use will be summarized here.

The IEUDB gives a figure of 1% in 1974 for fraction of purchased energy use for space conditioning and lighting in the manufacturing sector overall. This is probably too low. In the same table that space conditioning and lighting data are presented, the non-specified energy uses (i.e., excluding direct heat, process steam, raw materials, machine drive, electricity generation, electrolytic process, coke production, and space conditioning and lighting) are shown to add up to 21% of the total energy use in manufacturing. We suspect that some of the building energy use in manufacturing is erroneously shown under this heading. The data also show that about 17% of purchased electricity in manufacturing was used for building services in 1972.

In the food industry, electricity for lights and HVAC accounted for 18% of purchased electricity in the meat packing industry (SIC 2011). The respective fractions of electricity for lights and HVAC in other branches of the meat industry were lower: 2% in sausage making (SIC 2013), 9% in poultry dressing (SIC 2016), and 11% in poultry and egg processing (SIC 2017). The data clearly show that within the meat products (SIC 201) group, meat packing (SIC 2011) is the major energy consumer. The fraction of purchased electricity used for lighting and HVAC in SIC 203, canned and preserved fruits and vegetables, is 16%, comparable to the figure in the meat industry, and, although bakery products (SIC 205) not particularly important for California, this industry used 30% of its purchased electricity for lighting.

Under metal fabrication, there are diverse industries. The data quoted for 1977 for energy consumption by General Motors (which is not classified under SIC 34, although many of its manufacturing processes are similar to fabricated metal products) show that 31.7% of the purchased energy went for HVAC in the plant, and 3.3% of the purchased energy was used in lighting. The IEUDB authors remark that "in many companies, non-process energy demands are large, often as much as 50% of the total requirements... Significant savings - of 20 to 35% - may result from improvements to buildings."

II.7. ASHRAE Industrial Energy Conservation Awards

We assessed industrial buildings that won ASHRAE awards for energy conservation in buildings. Our goal was not representativeness in the data (the buildings were clearly outstanding examples of what can be done), but we wanted to get an idea of the upper limits of conservation potentials with existing commercialized technology, the measures that contribute significantly to the energy efficiency of these award-winning buildings.

In Appendix 6 we present short summaries of special conservation features found in the facilities that have won ASHRAE awards. Some are new facilities and some are retrofits. For most, the following data are given:

1. conditioned floor area,
2. percentage of floor space by activity and working hours, and
3. energy consumption and costs (monthly bills or end-use profiles are not published).

Conservation technologies in these buildings can be listed as:

1. gas-fired radiant heating of floors,
2. use of high-pressure sodium in lighting,
3. changing absorption chillers to centrifugal chillers in areas where gas prices are high,
4. process heat recovery,
5. use of ground water coupled heat pumps, and
6. direct use of well water for cooling.

II.8. Summary of Literature Survey

Data on non-process energy use in industrial buildings are scarce, sporadic, and widely variant from source to source. Energy use in this sector seems not to be perceived as an important part of overall industrial activities; however, the sporadic data suggest significant energy use for non-process purposes in industrial buildings.

III. COMPARISONS OF VARIOUS DATA BASES

Industries in which process use is the overwhelming factor, including industries requiring minimal buildings, will not be considered in this analysis. Our discussion will focus on industries that use large quantities or high percentages of energy for building services. For example, fabricated metal products, SIC 34, ranks seventh nationally in industrial use but uses only 3.5% of total energy consumed by the top ten industries. In many companies in this category, non-process energy demands are large, often as much as 50% of total requirements. Such large demands usually result in conservation efforts in this area, because, compared to process improvements, building services conservation can almost always be accomplished with small capital investment and with technology that has short payback periods.

California industries that, according to ERC groupings, show 50% or more of purchased energy used for building services are seen in Figure 6; they are home electronics (6-2), light machinery and similar (7-5), misc. manufactured products (7-11), spacecraft and missiles (7-2), furniture (7-9), optical and medical instruments (7-8), apparel (7-10), electronics and components (6-4), computers and office machinery (6-1), communications equipment (6-3), engineering and scientific instruments and controls (6-5), and wood containers (7-13). These 12 groups use approximately 52.4 TBtu/year in California, which is 11.7% of the total surveyed use.

Figure 7 shows the percent of service energy which is electricity versus the total service energy for California industries. Again, such industries as light machinery and similar (7-5), electronic components (6-4), computers and office machines (6-1), aircraft (7-1), spacecraft and missiles (7-2), and communications equipment (6-3), appear to be heavy consumers of electricity for lighting and air conditioning and ventilation and thus should be excellent candidates for cost-effective conservation measures.

III.1. Comparisons of California Industries with National Industries

The extent to which comparisons can be made between California and national energy use is constrained by limited data. ERC data were disaggregated to conform to the SIC scheme, and values of total fuels and electricity purchased by two-digit SIC were compared to California values based on the U. S. Department of Commerce, Bureau of the Census 1977 Census of Manufacturers to see if the two sources generally agree. Table 2 is a comparison of 10 National and California two-digit SIC values showing relative importance, and total fuel and electricity purchased compared to ERC derived totals for California. It should be kept in mind that neither the Industrial Energy Use Data Book nor ERC included all categories in their respective surveys, and ERC surveyed only portions of certain two-digit SICs. Also indicated in Table 2 are the relative rankings of industrial energy use nationally and within California.

The relative importance of industries within California differs from that nationally; most notably, petroleum refining, stone-clay-glass, and food rank 1,2,3 in California purchases of total energy, whereas the first three nationally are chemicals, primary metals, and paper.

Figure 6
Percent of Total Purchased Energy Use which is Used for Services versus Purchased Fuel and Electricity
(All Site Energy)

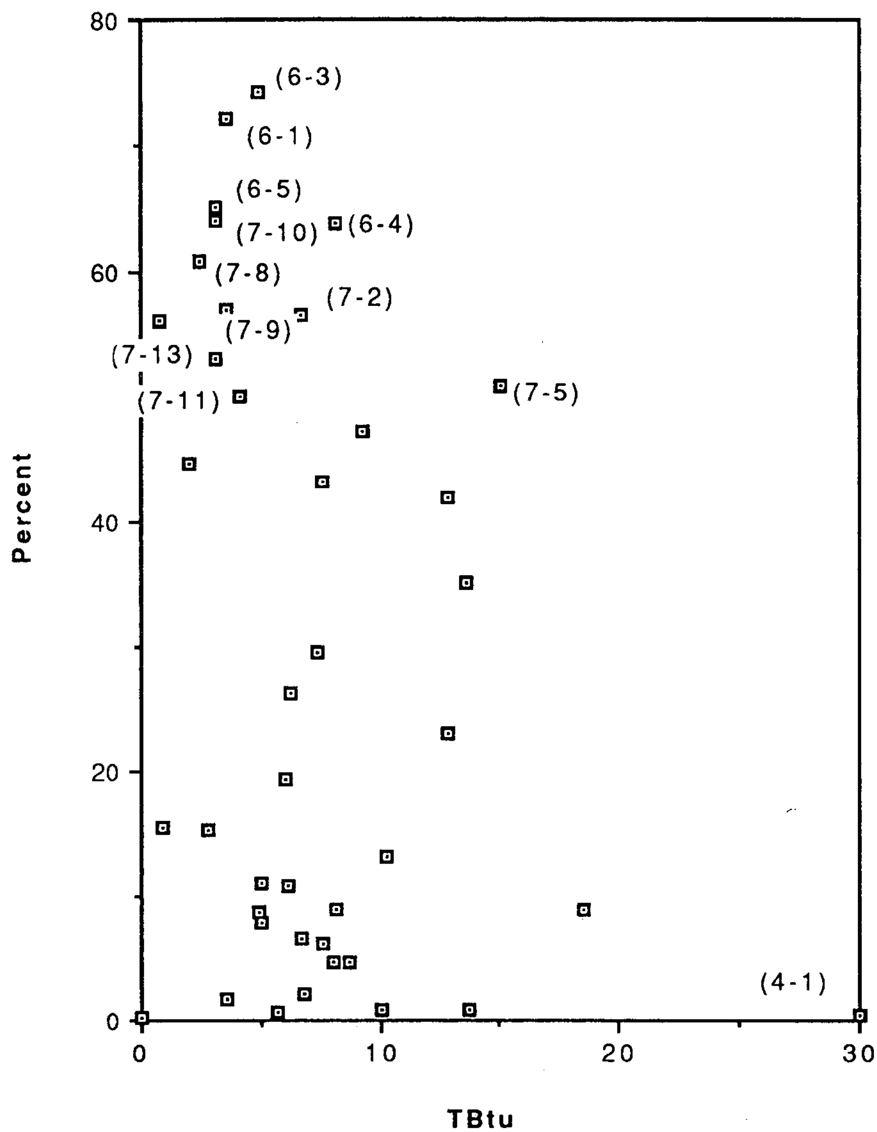


Figure 7
Percent of Service Energy which is Electricity versus Total Service Energy (Electricity + Fuel)

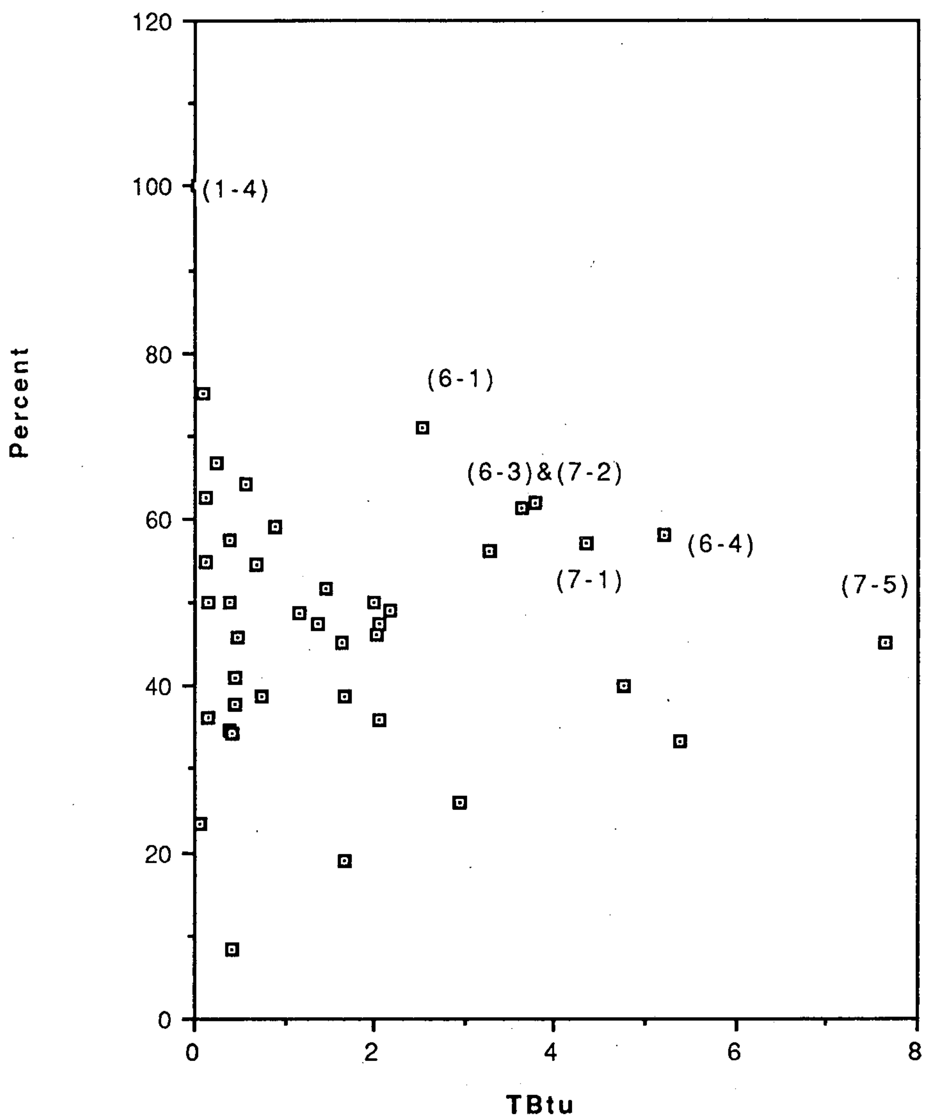


Table 2

Coarse Comparison of National and California Industrial Purchased Fuel and Electricity

SIC	Description	National		California		
		Total Purch'd Energy(1) TBtu	Nat'l Rank	Calif. Rank	Total Purch'd Energy(1) TBtu	Total Purch'd Energy(2) TBtu
20	Food	980.5	6	3	98.5	44.8
22	Textiles	337.6	9	10	5.2	6.0
26	Paper	1293.3	3	6	36.7	7.4
28	Chemicals	2939.5	1	4	60.9	62.6
29	Petroleum, coal	1288.8	4	1	134.9	84.0
32	Stone, clay, glass	1263.3	5	2	107.3	62.2
33	Primary metals	2370.3	2	5	51.3	47.5
34	Fabricated metals	404.3	7	8	25.6	29.1
35	Machinery	336.5	10	9	12.5	12.9
37	Transportation	389.1	8	7	26.2	27.2

Sources: (1) Industrial Energy Use Data Book(1980)
(2) ERC(1980)

To the extent possible a three-digit SIC level comparison between national and California data was made for building services energy end use to check agreement and consistency of data sources. The source of California data is the ERC report, and that for national data is the Industrial Energy Use Data Book. A cursory glance at Table 3 shows that reasonableness of consistency and agreement among various end uses varies considerably. Looking at the first category, meat packing SIC 201 we see that: Column 4 shows California purchases of energy represent only 4.9% of national energy use but 8.9% of the national electricity purchases. We can partly see the high share of electricity purchases in lighting and air-conditioning/ventilation energy use, where California supposedly used 13% of the national SIC 201 electricity for lighting and 24% of the national SIC 201 electricity for air conditioning/ventilation. In terms of fuel use in SIC 201, apparently California consumes 15% of fuel used nationally for space heating, resulting in California using energy for building services equal to 16% of the national energy use for building energy services. Another way of stating this is the last column of Table 3 indicates the total energy used by meat packing, SIC 201, in California; 11.2% of energy used appears as building services compared with only 3.5% nationally. It is not known why or if this factor of three times higher energy use for building services in SIC 201 in California is real. Many other equally puzzling comparisons may be made throughout this table. Figs. 8 - 10 depict these comparisons for meat packing SIC 201, dairy SIC 202, grain milling SIC 204, bakery SIC 205, fats and oils SIC 207, beverages SIC 208, and misc. SIC 209.

Table 3

3 Digit SIC Energy End Uses; California vs. National for SIC 20; Food. (All Values Purchased Energy, TBtu)

SIC	Descriptor		Total	Electricity	Lighting	A/C Vent	Space Heat	Bldg Services as % of Total
201	Meat Packing	CA	5.0	1.5	.21	.15	.20	11.2
		Nat'l	103.6	16.7	1.58	.63	1.36	3.5
202	Dairy	CA	6.7	1.5	.07	.10	.27	6.6
		Nat'l	92.5	14.3	.81	.28	9.78	11.8
204	Grain Milling	CA	4.9	1.2	.10	.05	.28	8.8
		Nat'l	108.7	24.4	1.30	1.32	2.60	21.4
205	Bakery	CA	4.9	.74	.15	.05	.20	8.1
		Nat'l	51.4	8.61	3.10	-	7.35	20.3
207	Fats,Oils	CA	6.6	.90	.04	.03	.08	2.2
		Nat'l	105.2	9.89	.58	.07	2.95	3.2
208	Beverages	CA	8.5	1.8	.09	.05	.26	4.7
		Nat'l	101.2	16.2	3.06	3.88	3.91	10.7
209	Misc.	CA	8.2	1.5	.16	.12	.45	8.9
		Nat'l	22.1	5.27	.67	.38	1.0	9.3
20	Food Totals	CA	44.8	9.2	.82	.50	1.74	6.8
		Nat'l	584.7	95.4	11.02	6.56*	28.9	8.0

* SIC 205 is not included in National Data.

Sources: ERC [8] for CA data;
CA data from [8] does not contain CA-important SIC 203 (canned, frozen fruits, vegetables), or SIC 206 (sugar processing).

Industrial Energy Use Data Book [6] for National data.

Figure 8
California Industrial Energy Purchases by Fuel Source as a Percentage of National Energy Purchases by the same Fuel Source

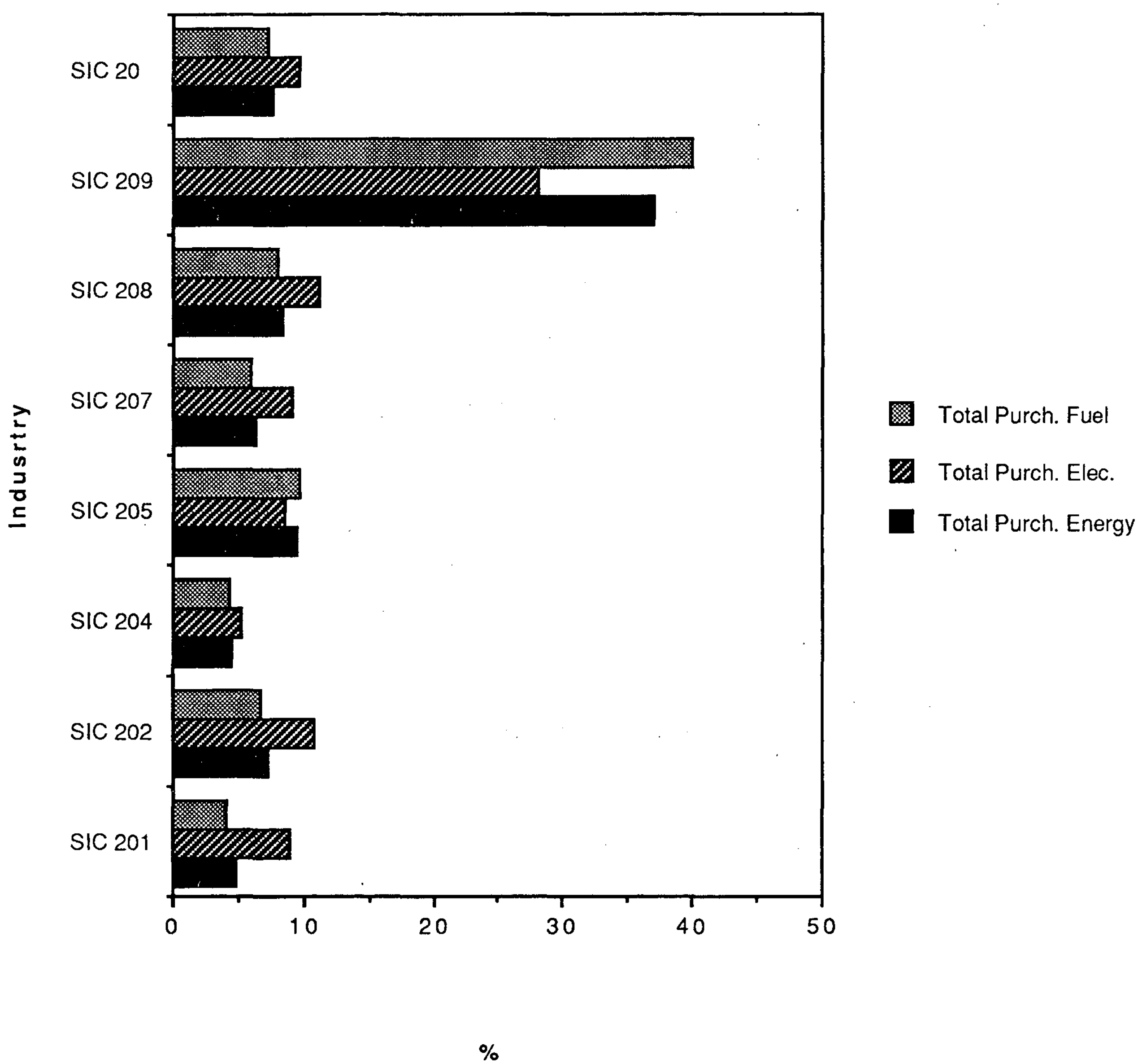


Figure 9
California Energy Use in Industrial Building Services by End Use as a Percentage of National Energy Use by the Same End Use

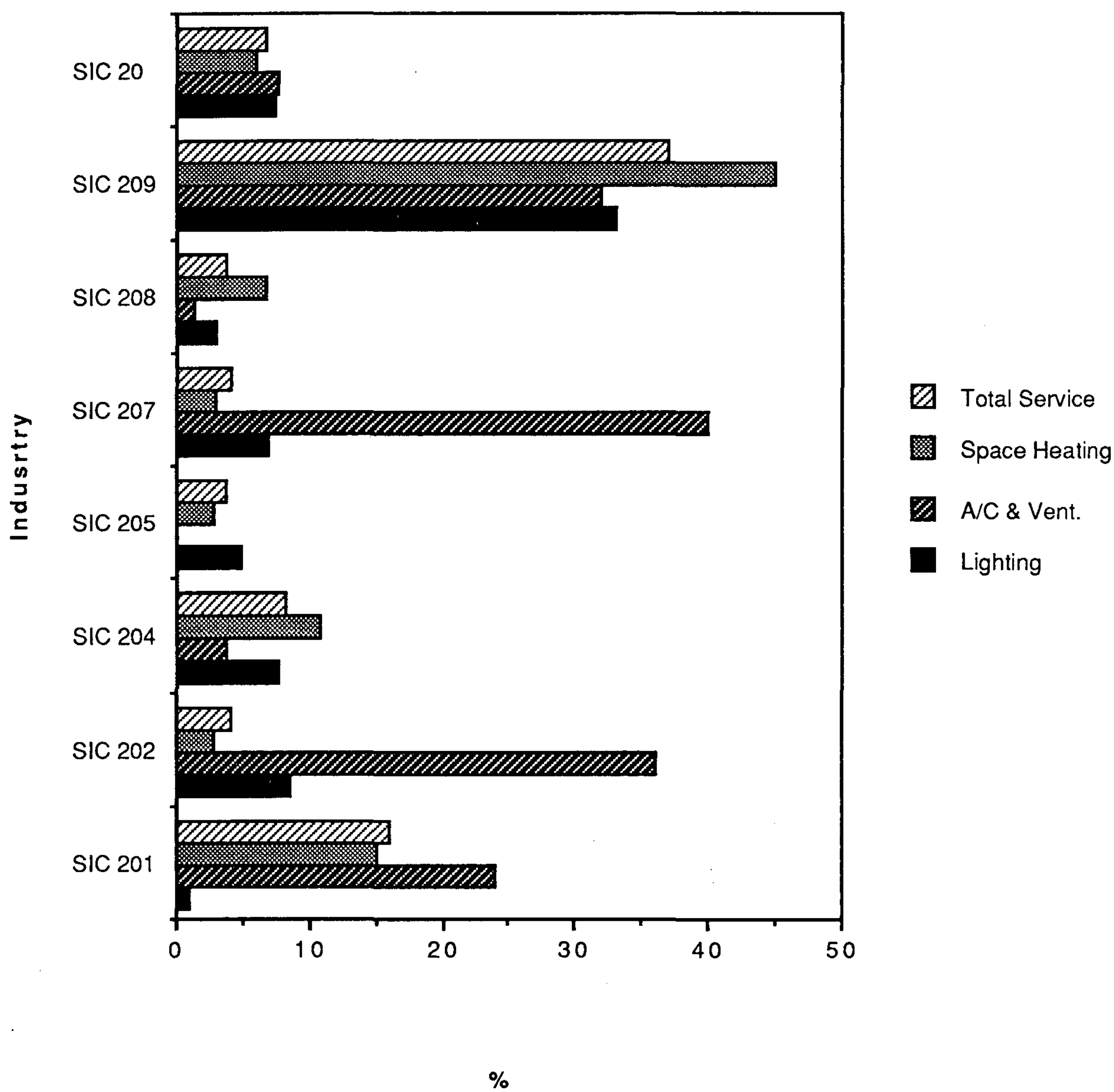
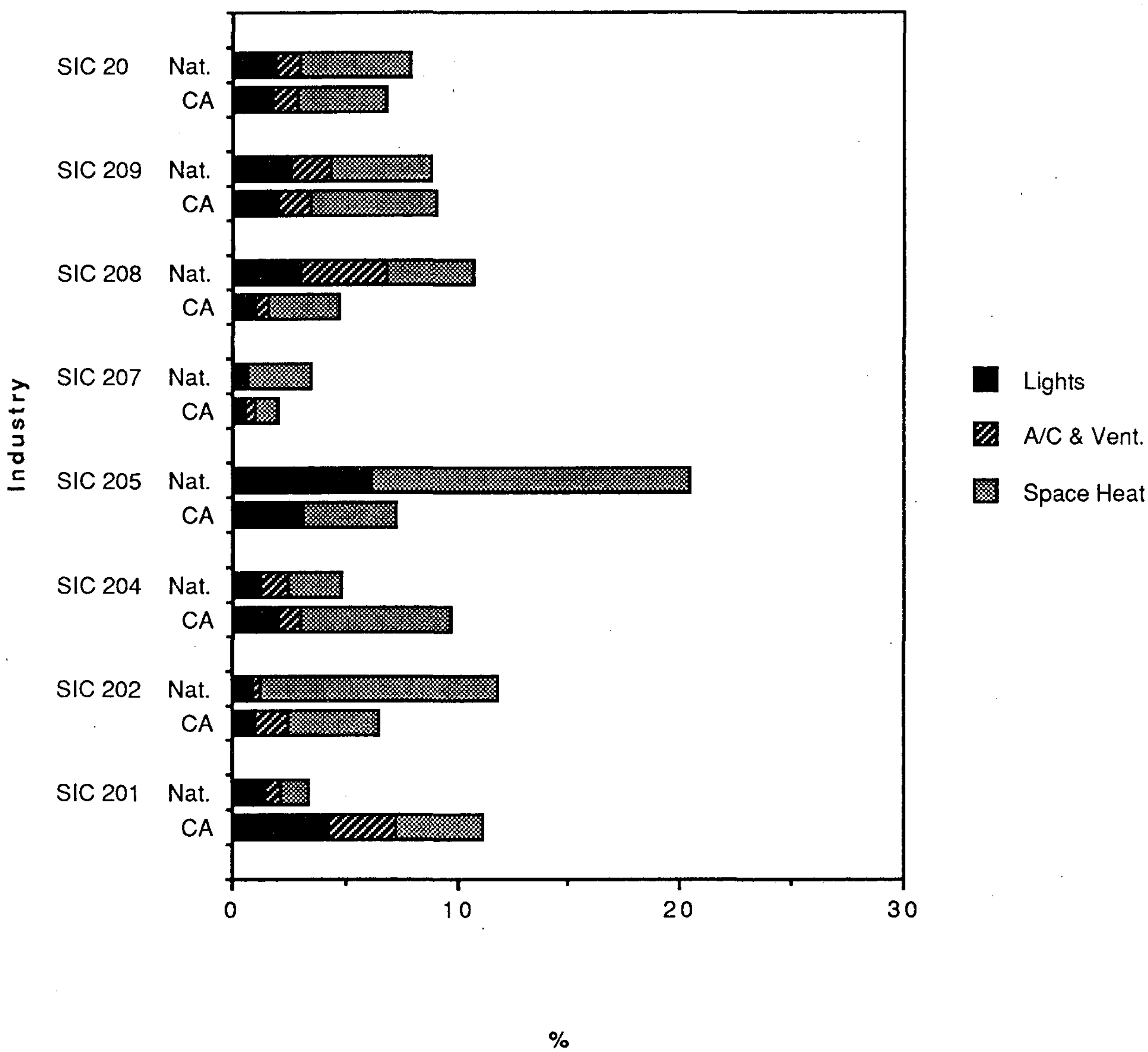


Figure 10
Energy Use in Building Services as a Percentage of the Total Site Energy Use



Review of the Table 3 data indicates that energy use by categories in California has a different pattern than energy use in the same categories nationally. This may suggest that factors such as climate and relative energy costs, which vary considerably from region to region, do not seem to have an impact on the energy use pattern of California industries. Alternatively, the data bases are not sufficiently detailed and/or accurate to show these effects. Another possibility is that these apparent anomalies may be explained by a detailed consideration of how process energy use affects energy use for building services.

III.2. Comparison of Regional Audit Data With ERC Data

Only qualitative comparisons can be made between Regional Audit data and ERC data. The principal reason for this limitation is that ERC has grouped several four-digit SICs together whereas the PG&E based data are not thus aggregated. Secondly, ERC data are representative of statewide use rather than use in PG&E's service territory only. Nonetheless, we compared the fractional use of electricity for two four-digit industries. PG&E audit data for SIC 3573 (the computer industry), and SIC 3674 (the semiconductor industry) were compared to: ERC audit data groups 6-1 and 6-4. Group 6-1, computers and office machines, is in reality SIC 357 and includes computers, peripherals, typewriters, calculators, and scales and balances, where computers account for 94% of the value added of this group. Group 6-4 is in reality SIC 367 electronic components and accessories, including electron tubes, SIC 3671; semiconductors, SIC 3672; capacitors, SIC 3673; resistors, SIC 3674; coils and transformers, SIC 3675; connectors, SIC 3676; and electronic components not elsewhere classified, SIC 3679. SIC 3672 constitutes over 50% of the economic activity of ERC Group 6-4, and SIC 3679 constitute another 25%; the remaining 25% is split approximately evenly among the remaining five industries. With these discrepancies noted above, the end use percentages may be compared in Table 4.

Table 4

Comparison Of Electricity End-Use Data From ERC Data, PG&E EUA California Data, and HBC National Data for SIC 35 and 36.
Data are shown as percentages (%) of total site energy use.

End Use	SIC 36			SIC 35		
	ERC Group 6-4 SIC 367	PG&E EUA SIC 3674	HBC SIC 36	ERC Group 6-1 SIC 357	PG&E EUA SIC 3573	HBC SIC 35
Lighting	14.1	12.4	9.4	25.0	26.7	11.2
A/C Ventilation	60.9	39.2	27.6	49.6	36.4	22.5
Motors	8.1	13.0		7.5	16.4	
Process Heat	12.1	25.7		14.6	7.3	
Miscellaneous	4.7	9.7		3.3	13.2	

As mentioned earlier in this report, there is considerable plant by plant variation in end-use categories within the same four-digit SIC. For example, PG&E audits show that electricity use for air conditioning in the computer industry, SIC 3573, varies from negligible to over 70% of total electricity purchases, and, in the semiconductor industry, SIC 3674, it ranges from approximately 5% to nearly 70% of total electricity purchases.

Plant by plant energy use comparisons should be a part of a careful analysis of customer energy use which examines site-specific characteristics, going beyond familiar parameters (e.g. climate, operating hours per week, energy use per square foot) to include such parameters as purchased energy per employee, employees per unit of product, and other indicators which might help researchers estimate the level of automation at various plants. Variations in levels of automation might explain some of the large discrepancies in energy end use among plants with the same four-digit SIC.

HBC reports 84.4% of all non-process energy is used for space heating nationally, 8.0% for A/C ventilation, and 7.6% for lighting. This differs from the ERC findings for California, which were 52% for space heating, 31% for A/C ventilation, and 17% for lighting.

IV. LBL WORK WITH THE PG&E ENERGY UTILIZATION AUDIT (EUA) INDUSTRIAL DATA BASE[2]

The EUA data base contains auditor estimates of the percentages of both purchased natural gas and purchased electricity consumed by various end uses. The eight end uses identified for electricity are: 1) lighting, 2) air conditioning (which we assume includes all necessary motors and controls), 3) refrigeration, 4) process heat, 5) space heat, 6) motors, 7) hot water, and 8) miscellaneous (which must include a wide variety of uses such as office equipment and computers). The seven end uses identified for natural gas are: 1) space heat, 2) hot water, 3) boiler for building-heat, 4) boiler for process 5) direct process heat, 6) cooking and 7) miscellaneous (which could include gas-driven cogeneration or absorption cooling).

Only a preliminary investigation of this data base was possible in the time available. Before undertaking this analysis, we systemically eliminated irrelevant and marginally relevant cases in the PG&E data base. We first eliminated all facilities not included in the SIC numbers of 2000 to 3999. This left 11,383 cases, which (because of the structure of the data base) actually represented about one fourth this number because repeat visits or callbacks appear as separate cases though they are not.

The number of cases to be analyzed was reduced further when we imposed the requirement that each facility examined be enclosed in a building because our investigation focuses on building services. This eliminated such facilities as tank farms, pumping stations, and the like. Due to apparent anomalies in the data, we further required that the floor area of each facility be at least 2,000 square feet and the annual number of hours of operation had to exceed 1,050 (20 hours per week). Also, we attempted to eliminate facilities that housed more than one industrial activity or mixed industrial activity with commercial activity because analyzing such facilities is very complex.

Recognizing that the economy is dynamic and energy requirements of particular customers change with it, we tried to eliminate these complicating factors from the study by excluding buildings which the auditors recognized as having changed operating hours, occupancy, or production; we also excluded facilities that undergone other substantial changes.

After a preliminary assessment of the selected cases, 1,663 cases representing different sites showed entries that represented with one call-back follow-up, 862 cases indicated a second call-back, and 274 showed three; only 9 showed four call-back entries. Because we noticed that energy conservation measures appeared most frequently in the first call-back data, our analysis was restricted to data obtained in the initial visit and the first call-back. We did not determine for any case the dates of the original audit or the first follow-up call-back.

Because of these restrictions, and other reasons, the number of variables per case could be reduced from 798 to 438, which permitted statistical analyses to be made without memory difficulties or high computation costs.

This culled data base was used to examine portions of five industries, chosen in part because of their diversity and/or their relative importance as growth areas in the California economy. The SIC ranges investigated are:

---

[2] Other California utilities were invited to submit audit data; however, most indicated they did not have such data in a readily usable form.

1. Meat Products, Meat Packing plants, Sausages and other prepared meats, and Poultry Dressing plants, SIC 2000 - 2016, hereafter simply referred to as Meat Packing.
2. Frozen Fruits, Vegetables and Specialties, SIC 2037 - 2038, hereafter referred to as Frozen Fruits.
3. Electronic Components and accessories, electron tubes, cathode ray television picture tubes, semiconductors and related devices, electronic capacitors, resistors, coils, transformers, connectors and components not elsewhere classified, SIC 3670 - 3680, hereafter referred to as Electronics.
4. Transportation, motor vehicles and equipment; car, truck and bus bodies, parts and accessories; truck trailers; aircraft, engines and engine parts; and aircraft equipment not elsewhere classified, SIC 3700 - 3730, hereafter referred to as Motor Vehicles, and,
5. SIC 3800 - 3900 Instruments and Related Products, SIC 3800 - 3900, hereafter referred to as Instruments.

IV.1. The Purposes of This Investigation

The principle objective of this investigation was:

1. to estimate (as closely as the data permit) the magnitude and type of energy end use which controls the working environment for either the occupants or in special cases the process itself (e.g., certain industrial products require rigid controls of air particulates, humidity, and temperature),
2. to examine potential and implemented conservation opportunities from industry to industry by end use, and
3. to ascertain the value of a data base to assist in the problems of electrical and total energy demand forecasting.

Many lines of investigation can be identified for further analysis. For example, from a marketing perspective, one could estimate the fraction of the electronics industry that is presently air conditioned. Or, a close study of the way fuel is used could determine whether or not waste heat from a process could be used to heat or cool buildings.

IV.2. Results

In the following sections, we present some results from an analysis of end uses in building services, and we give estimates of potential and implemented conservation measures. Where possible, estimates resulting from this data base will be compared with estimates of other investigators. One difficulty in making quantitative comparisons is that the PG&E data base is regional and therefore covers only a segment of California industry. Also, this data base does not contain information on use of fuels other than natural gas (although it does indicate whether facility managers may access another fuel source). For this reason, the annual gas consumption data may not reflect the total annual fuel use by the facility. Also, it is presently not possible to ascertain whether cogeneration installations exist at the facilities or if the gas sold by PG&E represents all of the natural gas used at the site.

Electricity consumption across the five selected categories of industry, disaggregated by end uses, is shown in Figure 11. The contribution to total electricity consumption from lighting ranges from 9.5% in Frozen Fruits to 29.1% in Instruments. Air conditioning is almost nonexistent in Frozen Fruits but consumes nearly 35% of the total electricity use in Instruments. There is hardly any use of refrigeration in the Motor Vehicle industry but 59% of purchased electricity is used for refrigeration in the Frozen Fruit industry. Electrically activated process heat is not used in the Frozen Fruit industry but consumes 20% of the Electronics Industry electricity. Motors require from 8.4% of electricity purchased in Instruments to 36.5% in the assembly-line dominated Motor Vehicle industry. None of the five industries selected had significant electrical space heating. The miscellaneous use ranges from 5% to nearly 17%, and use of electricity for hot water is negligible.

Figure 11 also displays total annual electricity consumption per square foot for each of the five industrial categories. These quantities are usually called Energy Use Intensities (or EUIs). The values vary by nearly a factor of three from about 20 to approximately 60 kWh/ft^2, with Instrument Manufacturing on the low end and Electronics manufacture on the high (note that Motor Vehicles category is apparently dominated by one or more very large and intensive users).

Although lighting use is somewhat seasonal and probably fluctuates throughout the day, it may still be meaningful to look at demand in W/ft^2, which reflects the hours of operation. Instrument Manufacturing, Electronics, and Motor Vehicles appear to use about 2.0 to 2.3 W/ft^2 for lighting. Frozen Fruits and Meat Packing appear to use about 0.8 and 1.2 W/ft^2 respectively.

Because air conditioning is seasonal, a comparison of this electricity end use can be based on annual consumption. Figure 11 shows kWh/ft^2 estimated electricity use for air conditioning. As expected, this need is minor in Frozen Fruits and Meat Packing but is very important in the Instrument and Electronics categories. The Motor Vehicle industry's use of air conditioning is skewed by data from a few very large plants but still appears important.

Electric motor energy consumption is probably not seasonal. Considering the operating hours, electricity use intensity in W/ft^2 for motors ranges from about 0.5 W/ft^2 in Instruments, about 1 W/ft^2 in Electronics, to the area-weighted value for the Motor Vehicle industry of 3.5 W/ft^2. For the Frozen Fruits and Meat Packing Industries, electricity use intensity for motors is about 1.5 W/ft^2.

A summary of the gas use in these industrial categories is shown in Figure 12. Gas space heating ranges from 5% in the Motor Vehicle facilities in the data base, to more than 58% in the Instrument Manufacturing industry. Gas-fired water heating is important in the Meat Packing industry and gas-fired boilers for heating buildings require nearly 74% of Motor Vehicle gas consumed. Gas boiler process heat is responsible for more than 86% of the gas use in the Frozen Fruit industry. Gas-fired process heat is important in the Instrument and Meat Packing industries, and cooking requires about 4% of Meat Packing gas use. Miscellaneous uses do not exceed 3% in any of these industries.

Instrument and Electronics segments are the least intensive users requiring about 40 KBtu/ft^2, and the Frozen Fruit industry has the highest EUI for gas: approximately 400 KBtu/ft^2. Meat Packing shows a gas EUI of only about 200 KBtu/ft^2.

Figure 11
Electricity Use Intensity for Five Selected California Industries

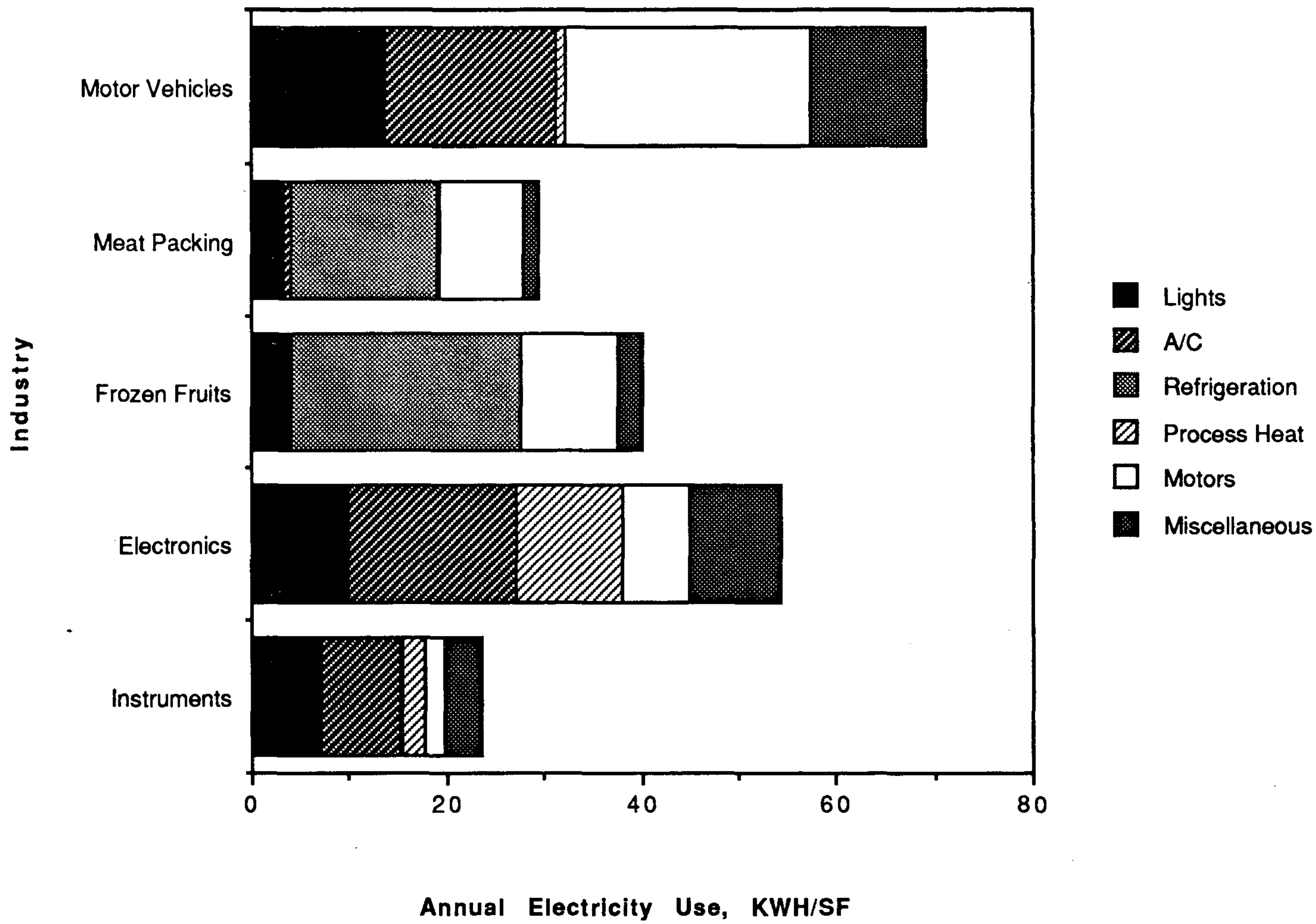
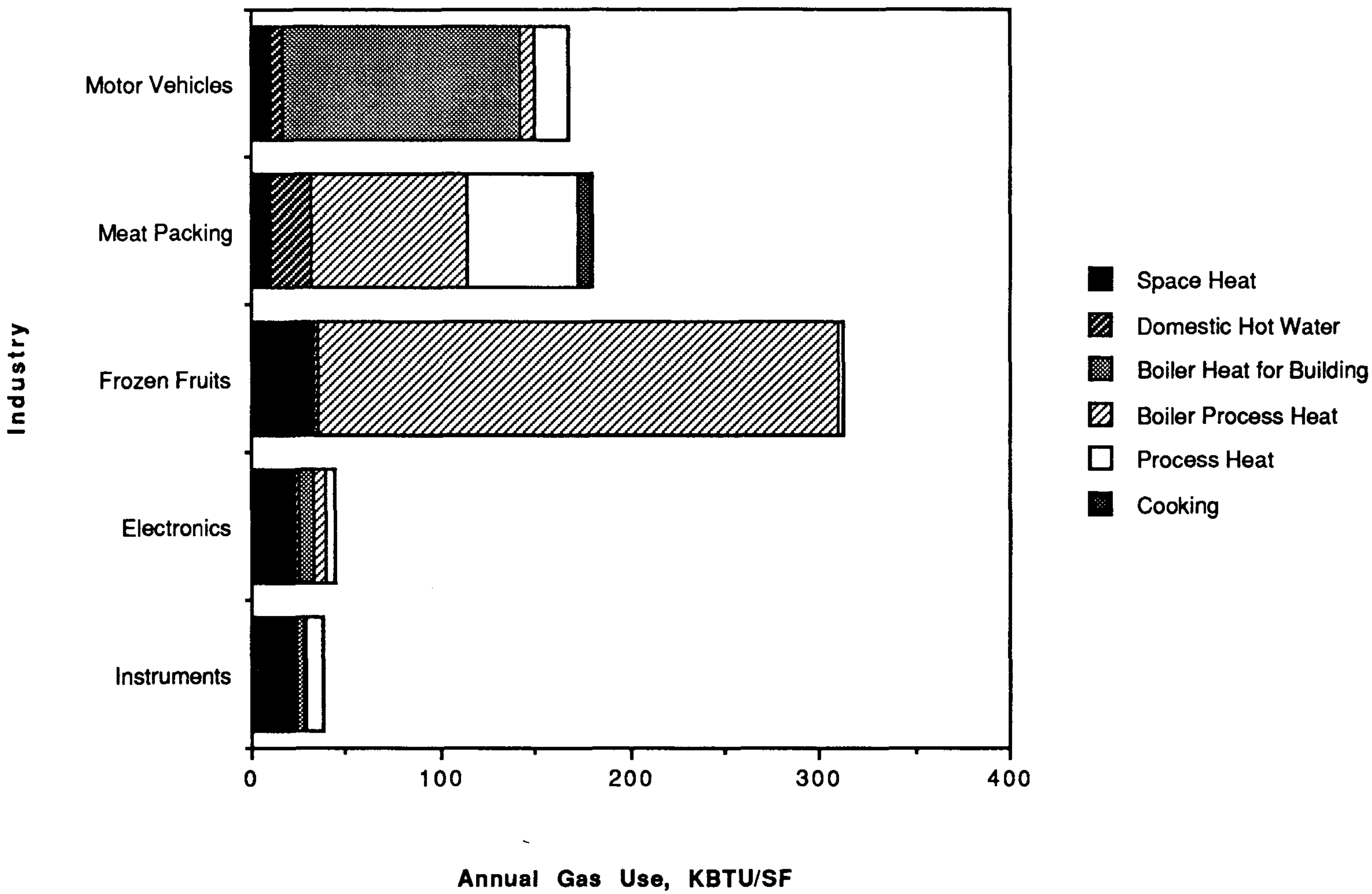


Figure 12
Gas Use Intensity for Five Selected California Industries



One of the most prevalent uses of natural gas is for space heating. Because of California's mild winters and internal heat gain from process activities, heating demands generally appear small, but they vary by more than a factor of four. For example, Motor Vehicle buildings data for gas fired boiler heating of buildings appear to be significant while data for the other four chosen industries are negligible. As pointed out earlier, the Motor Vehicle Industry is dominated by a few very large facilities and distributions are heavily skewed as a result. The area-weighted value for boiler building heat in the Motor Vehicles category is about 125 KBtu/ft^2/year, which may be the result of open construction.

The annual energy use per unit floor area is dependent upon number of hours of annual operation. Total annual hours of operation from the selected categories in the data base are shown in Figure 13. There is variation among facilities within each category and also among industry groups. Four of the five categories show year-round operation for at least one of the cases audited. It is also interesting to note that the highest mean, over 5,000 hours annually, is Frozen Fruits, which might have been expected to show strong seasonal variations and fewer hours of operation than other industrial categories.

Perhaps the most complete overview of these five industrial categories can be displayed as average annual resource energy, shown in Figure 14. Using a conversion factor of 10,239 Btu/KWh, electricity consumption figures were then added to the Btu values from natural gas. (These values cannot be considered an accurate measure of the total resource use due to a number of factors, notably use of other fuels at many facilities. No accounting, for example, is given fuel for lift trucks or fuel switches that may have occurred whenever a more economical source could be obtained or for cogeneration supplying a fraction of electrical and thermal energy needs.)

It is interesting to note that the annual average energy use intensities of Instrument Mfg. and Electronics, (285 and 644 KBtu/ft^2) differ by more than a factor of two, and that the Frozen Fruit industry (920) exceeds by a large margin the EUI for such intense users of energy as Motor Vehicles (306). Again there is a large variation among members of the same industry, a result, in part, of other energy sources possibly in use and different activities facility to facility, or possibly of incorrect perceptions by the auditors, and data entry errors.

From the data presented in Figures 12 and 14, one can observe that the direct use of natural gas at sites represents only 14.4 and 6.5% of the resource energy used by the Instrument and Electronics industries respectively, but its use increases to 31.6, 36.3, and 55.0% of the resource base for the Motor Vehicle, Meat Packing, and Frozen Fruit industries respectively.

Figure 15 displays a few statistics concerning the sizes of conditioned buildings comprising the chosen industrial groups. The mean values for Instruments, Electronics, Frozen Fruits , Meat Packing, and Motor Vehicles are 37,000, 42,100, 73,600, 28,200, and 118,500 square feet respectively. [3] The corresponding median values are 23,000, 25,000, 69,800, 13,900, and 50,000 square feet. These data underline the difficulty of analysis of EUIs based on such widely varied statistics.

[3] Note that the sites with less than 2,000 square feet are dropped from this analysis.

Figure 13
Annual Hours of Operation for Five Selected California Industries

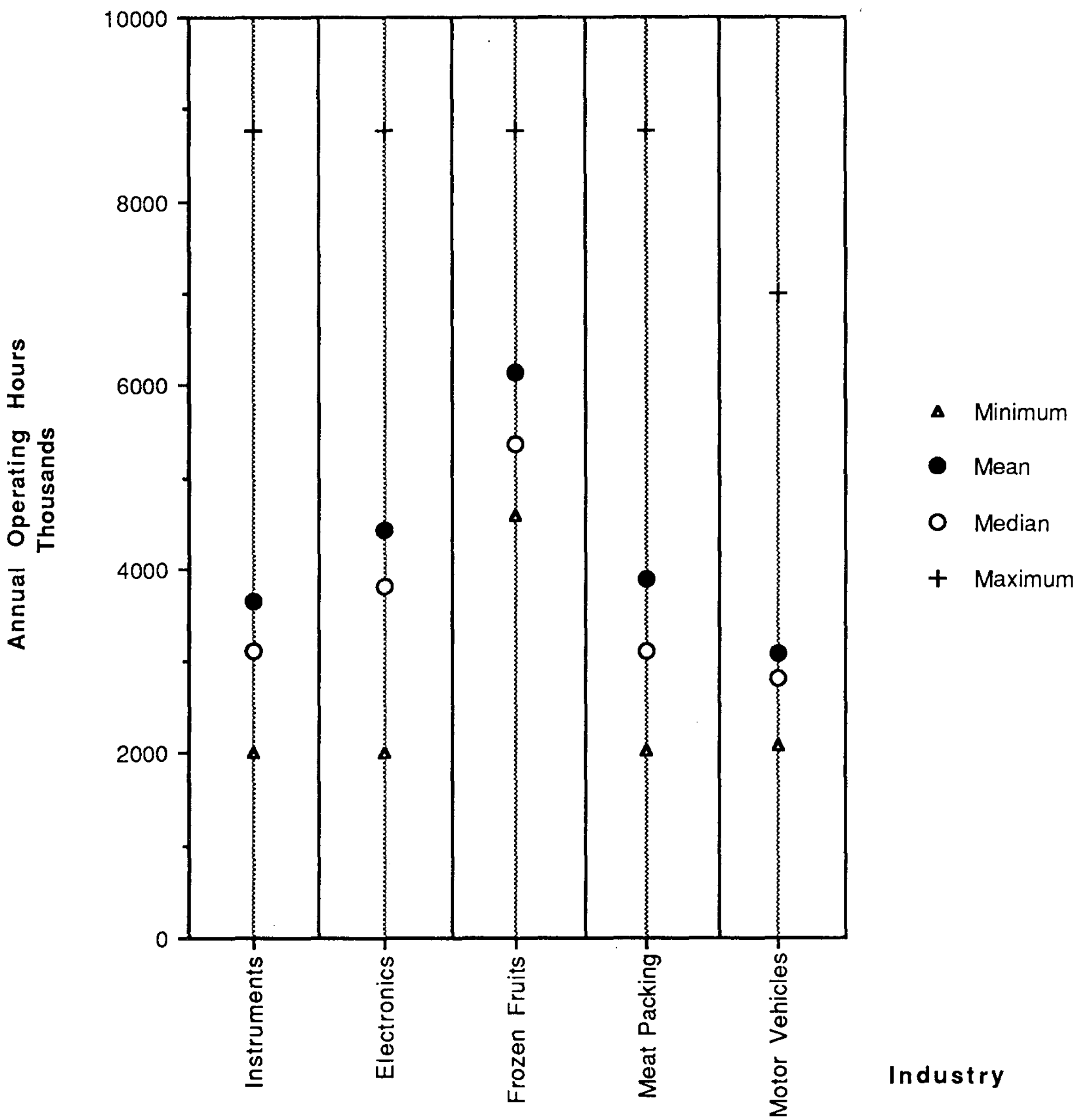


Figure 14
Annual Resource Energy Use for Five Selected California Industries

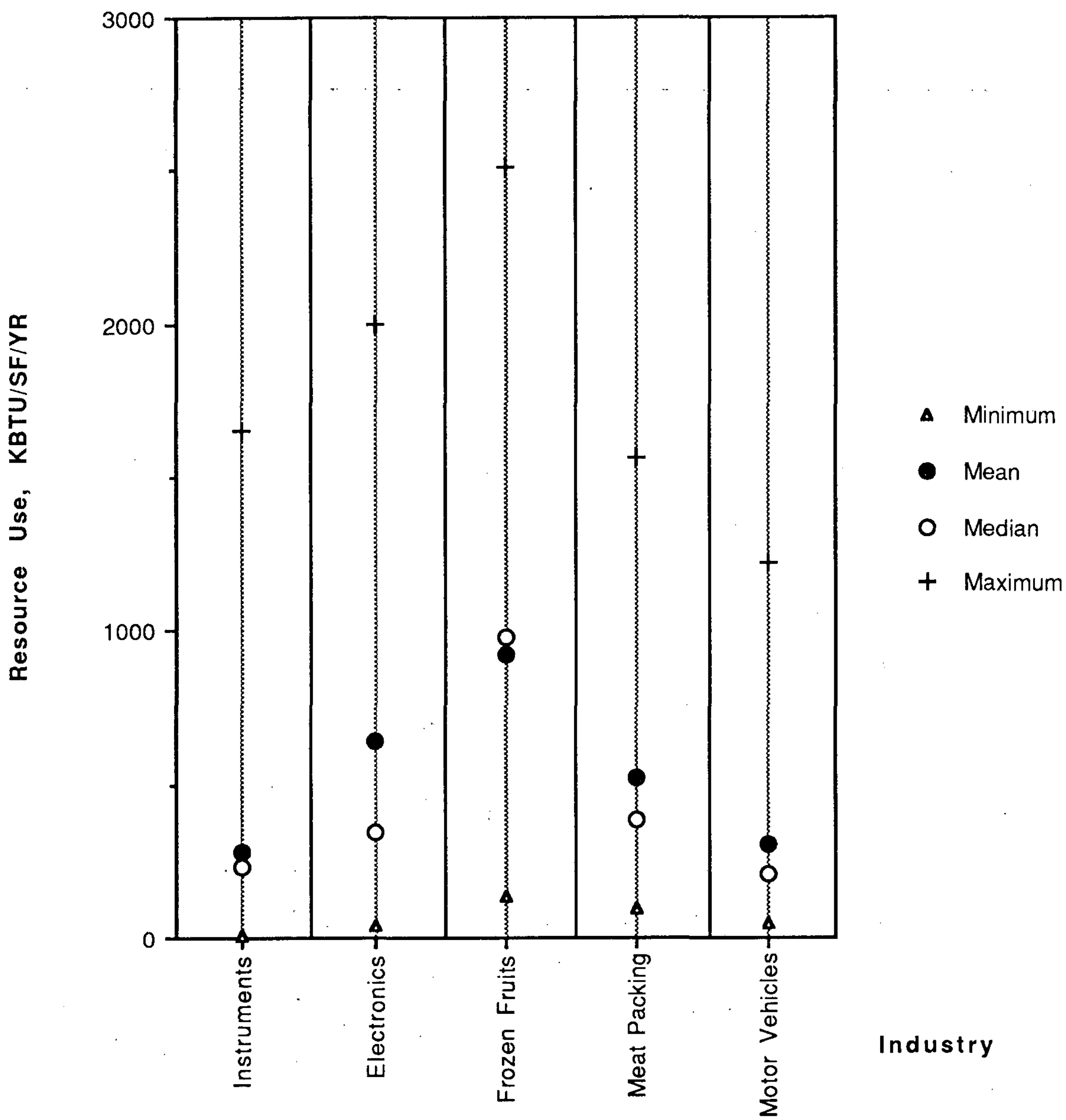
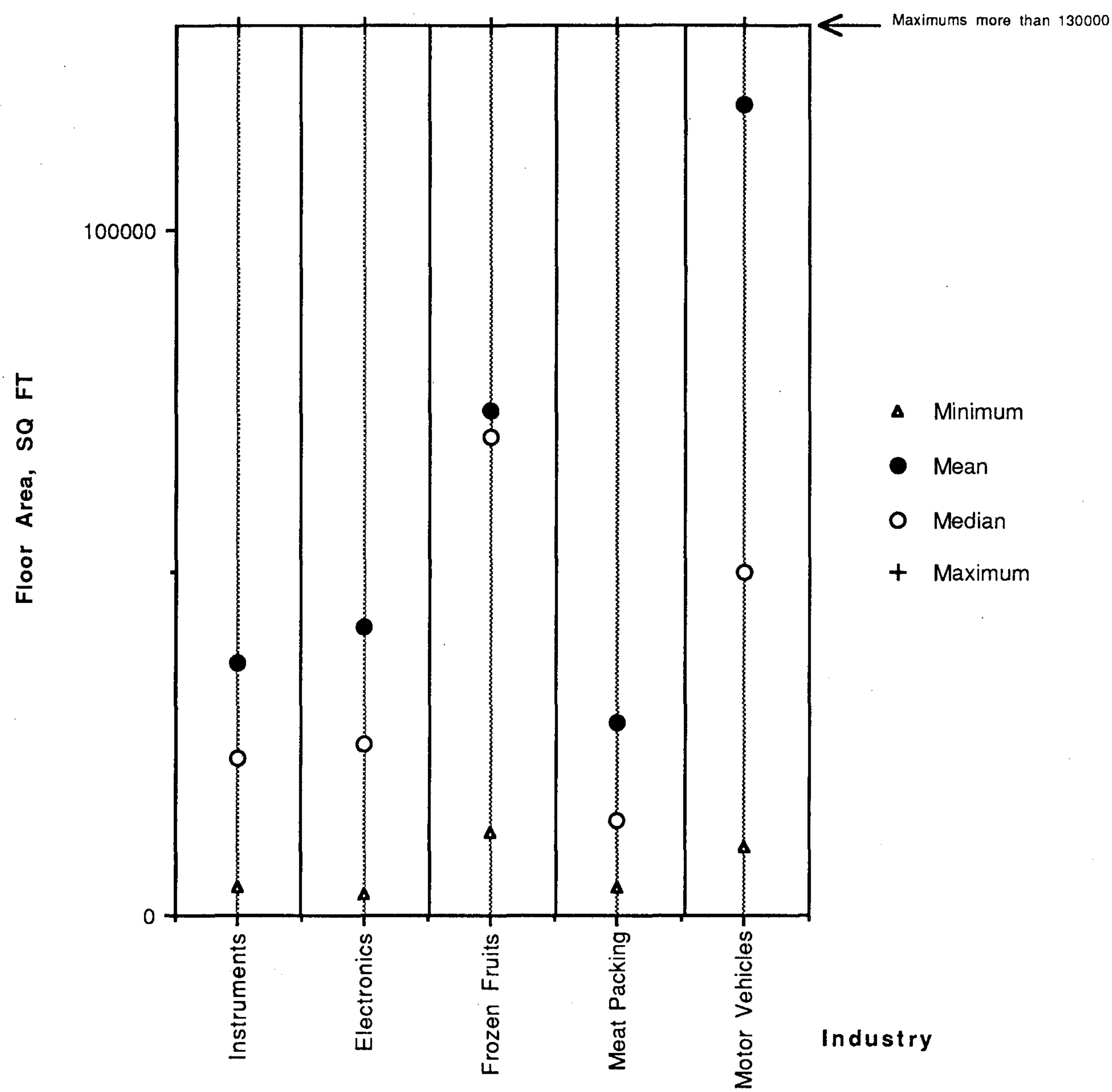


Figure 15
Facility Floor Area for Five Selected California Industries



A data base such as that initiated by PG&E can be used to derive strategic marketing information as mentioned earlier. An example is the level of saturation of a particular end use in a given industry (e.g. air conditioning, in the Electronics industry). The number of cases in which 5% or more of purchased electricity was used for air conditioning was 170 out of the 198 original cases selected. Also, of the 198 cases examined in electronics, all but 17 have access to alternate fuels.

IV.3. Comparison With Other Data

At least one other investigator, Booze Allen & Hamilton, had access to PG&E's EUA data base from which they reported interesting quantities such as the percentages of electricity consumption, disaggregated by end use, for a limited number of industries. Another qualitatively similar report containing this type of information is that of Energy Resource Consultants, which is being used by the California Energy Commission. It contains data that reflect state-wide energy use and will be compared where possible with our investigation of regional data from PG&E. Other investigations include data from regions whose climates are different and which are not expected to compare well with regional data from PG&E's service territory.

As mentioned earlier in this report, Energy Resource Consultants' report grouped industries somewhat differently than the SIC scheme. When we compare the five industrial segments chosen for study, we do not always find exact parallels in the ERC report, making precise comparisons unrealistic.

Tables 5 - 9 show percent end uses of gas and electricity as reported by ERC and extracted from the PG&E data base. ERC also includes other fuel (i.e. non-gas) end uses whereas the data base does not; therefore, "other fuel" use is not included in the tables that follow. The PG&E values shown for each industry are based upon the summed values of all cases which are also represented in the data presented by ERC. Another complication is that the PG&E data list entries for eight electricity end uses, and the ERC data list twelve combined end uses, some of which are almost exclusively served by gas and others electricity.

Table 5 shows PG&E data obtained from SIC 3800 - 3899 and from ERC groupings (7-8), optical and medical instruments, and (6-5), electronic instruments and controls. In contrast to data from PG&E's audits, ERC data appear to underestimate the importance of lighting and overestimate the importance of air conditioning. The disagreement between PG&E and ERC estimates in the remaining categories are not great except in the miscellaneous category. Unfortunately, neither analysis lists electricity for computers as a separate end use. Both recognize the importance of natural gas for space heating; however, ERC does not list gas fired boiler building heating separately as does PG&E. Thus PG&E data indicate that approximately 68% of the natural gas purchased is used for space heat; ERC has a lower estimate, and boiler supplied process heat, classed as steam by ERC, appears to be overestimated in the ERC report.

Table 5

Comparison of PG&E Data with ERC: Instruments(SIC 38)

Electricity	**PG&E**	**ERC**		**Gas**	**PG&E**	**ERC**	
% End Use	**sums**	**(7-8)**	**(6-5)**	**% End Use**	**sums**	**(7-8)**	**(6-5)**
Lighting	29.08	18.0	21.1	Space Heat	58.49	52.7	56.3
Air Cond	34.73	58.0	48.9	Hot Water	4.17	-	-
Refrigeration	0.24	2.0	-	Blr Bldg Heat	10.06	-	-
Process Heat	10.49	7.0	14.3	Blr Process Heat	0.27	20.9	12.7
Space Heat	0.34	-	-	Process Heat	24.16	20.9	26.8
Electric Motors	8.43	10.0	12.0	Cooking	0.2	-	-
Hot Water	0.70	-	-	Miscellaneous	2.65	5.5	4.2
Miscellaneous	16.01	5.0	3.8				

Table 6 compares PG&E data from SIC 3670 - 3680 with data from ERC's group (6-4), electronic components and accessories. PG&E data indicate lighting is more important than ERC data suggest, but air conditioning is only about half as important as ERC data indicate. Process heat also takes a larger share of the total use than the ERC data estimate. Again, computers, which may make up a large part of miscellaneous, represent a higher percentage than in the ERC report. Space heat appears to take about 67% of gas use after we include boiler-provided heat for buildings. If boiler process heat and process heat are summed in each data source, we find close agreement.

Table 6

Comparison of PG&E Data with ERC: Electronics(SIC 36)

Electricity	**PG&E**	**ERC**	**Gas**	**PG&E**	**ERC**
% End Use	**sums**	**(6-4)**	**% End Use**	**sums**	**(6-4)**
Lighting	18.30	14.1	Space Heat	50.73	53.6
Air Cond	31.64	60.9	Hot Water	5.27	-
Refrigeration	0.09	-	Blr Bldg Heat	16.93	-
Process Heat	20.01	12.1	Blr Process Heat	14.54	21.1
Space Heat	0.44	-	Process Heat	9.91	25.3
Electric Motors	12.48	8.2	Cooking	1.04	-
Hot Water	0.18	-	Miscellaneous	1.58	-
Miscellaneous	16.86	4.7			

Table 7 compares PG&E data from SIC 2037 - 2038 with data from ERC group (8-7), miscellaneous food products. ERC appears to overestimate the importance of air conditioning by about sixteen-fold, and underestimate the importance of refrigeration by approximately two -fold. Electric motor use may also be overestimated by ERC by about a factor of two. PG&E data suggest that space heating is considerably less important than the estimates of ERC, but once again the sums of the boiler process heat and process heat from each source agree quite well. This segment of the food industry uses significant amounts of both electricity and gas in the processes.

Table 7

Comparison of PG&E Data with ERC: Frozen Fruits(SIC 20)

Electricity	PG&E	ERC	Gas	PG&E	ERC
% End Use	**sums**	**(8-7)**	**% End Use**	**sums**	**(8-7)**
Lighting	9.54	10.8	Space Heat	1.58	8.9
Air Cond	0.50	8.1	Hot Water	0.81	-
Refrigeration	59.06	30.4	Blr Bldg Heat	0.	-
Process Heat	-	-	Blr Process Heat	86.63	55.6
Space Heat	-	-	Process Heat	0.66	35.5
Electric Motors	24.52	50.7	Cooking	-	-
Hot Water	0.11	-	Miscellaneous	1.32	-
Miscellaneous	6.37	-			

Table 8 is a comparison of PG&E data from SIC 2000 - 2016 with data from the ERC group (8-1), meat products. ERC has overestimated the use of air conditioning and underestimated the importance of refrigeration. Gas in this industry is primarily used for heating and boiling water, sterilizing containers, and washing equipment. If the proportions of gas listed as boiler process heat, hot water, and process heat were summed and compared with ERC values for boiler process and process heat, close agreement would be seen.

Table 8

Comparison of PG&E Data with ERC: Meat Packing(SIC 20)

Electricity	PG&E	ERC	Gas	PG&E	ERC
% End Use	**sums**	**(8-1)**	**% End Use**	**sums**	**(8-1)**
Lighting	11.30	14.1	Space Heat	5.61	6.6
Air Cond	2.30	10.1	Hot Water	11.18	-
Refrigeration	51.24	35.6	Blr Bldg Heat	0.20	-
Process Heat	0.76	5.4	Blr Process Heat	44.39	75.7
Space Heat	0.19	-	Process Heat	31.62	11.1
Electric Motors	28.77	30.2	Cooking	4.26	-
Hot Water	0.29	-	Miscellaneous	2.74	6.6
Miscellaneous	5.14	5.4			

Table 9 is a comparison of PG&E data from SIC 3700 - 3730 with estimates of ERC group (7-3), Motor vehicles and related products, even though the comparison may not be from directly comparable processes. The electricity end uses compare quite well. Space heating seems to be underestimated by ERC where PG&E data show a large portion of this use supplied by boiler heated water. The boiler process and process heat appear to be overestimated by ERC somewhat. Because a great variety of processes exist in this industry, the apparent discrepancy may not be serious.

Table 9

Comparison of PG&E Data with ERC: Motor Vehicles(SIC 37)

Electricity	PG&E	ERC	Gas	PG&E	ERC
% End Use	**sums**	**(7-3)**	**% End Use**	**sums**	**(7-3)**
Lighting	19.64	23.4	Space Heat	5.08	48.1
Air Cond	25.45	23.4	Hot Water	4.34	-
Refrigeration	0.01	-	Blr Bldg Heat	73.91	-
Process Heat	1.42	6.75	Blr Process Heat	4.76	19.3
Space Heat	0.21	-	Process Heat	10.85	24.9
Electric Motors	36.52	38.2	Cooking	0.08	-
Hot Water	0.02	-	Miscellaneous	0.98	7.7
Miscellaneous	16.74	8.6			

IV.4. Summary of Utility Data Base Assessment

The advantages of establishing and maintaining a data base such as PG&E's are many, but the associated costs are considerable. In discussing the merits of such a data base, representatives from several utilities state that, in hindsight, information of this nature would have been very valuable to the company for marketing and resource planning.

The California Energy Commission would greatly benefit from a statewide industrial data base which could assist their forecasting efforts and provide insight to the economic trends within California. If such a data base is recognized as valuable to both utilities and the state, it seems reasonable that the costs of establishing and maintaining a statewide data base could be shared by utilities and the state.

Many other state agencies could reap important benefits from data of this nature. As California's population grows, strict land use planning including industrial siting will become mandatory and transportation and distribution networks will have to be well thought out and developed to increase efficiency and productivity and to minimize congestion.

A data base's reliability is important and deserves considerable attention in any future planning. As mentioned earlier, the constantly changing nature of industry means that a significant effort would be required to keep data reasonably current and accurate. As a first step, metered checks could be made and compared with estimated data to determine the magnitude of discrepancies.

V. SUMMARY AND CONCLUSION

Seven different sources of information and data have been identified for the analyzing energy use in building services in the industrial sector in California. Most of these are studies and/or projects sponsored by Department of Energy, California Energy Commission, or local utilities. The objectives of these studies were diverse: most aimed at industrial energy use in general and in one case the objective was to analyze energy use in commercial buildings. None of these studies were aimed directly at non-process energy use in industrial buildings except for the HBC study[7].

The sources of information for these studies are: data bases either prepared by local utilities, or in-house data bases of the contracting consulting firms who carried out the study, or data from census or survey reports prepared by several government agencies. The data used for most of these studies are from the period 1975-1985. In particular, the Industrial Energy Use Data Book [6] used data collected for 1975-1980 period. It is obvious that the data available are outdated to a certain extent and may not represent the present state of the industries in California.

Five of the studies are national although one does not present data for California. Three of these five studies based their data on a very limited number of examples; only IEUDB [6] has some representative coverage of industry as a whole. The study by ERC [8] covers 70% of industrial energy use in California and the study by BAH [2] covers 25% to 98% of electricity purchases and 9% to 57% of gas purchases in several SIC's in the PG&E service area.

All of the studies classified industries using the SIC system except for NBECS [10]. ERC[8] grouped industries into supergroups and studied the aggregates. Four of the studies provided end-use data for building services. Out of these four, IEUDB [6] reported air-conditioning and lighting energy use as a single combined category.

Comparison of the findings of these studies and/or databases is difficult because of the varying objectives of the studies, the format for reporting data, the way data are aggregated in each study, the varying coverage of industry in each study, and the different time periods from which the data come. The most relevant information for California comes from ERC[8] and the PG&E energy use database, which is used by BAH for their study[2]. ERC[8] data are mostly based on information from the U.S. Census Bureau Census of Manufacturers (1977). The PG&E database is based on data collected during 1981-1984 through audits and questionnaires. The PG&E database was the main source of data that required further investigation.

Although these studies addressed different objectives focusing in different areas, time periods and industries, they all pointed to the importance of non-process energy use in industry as an area of potential conservation. The situation is very promising in California where there is a concentration of industries like instrumentation and computer manufacturing, in which most energy consumed is for air conditioning and lighting.

In their report HBC[7] approximated building non-process energy use to be 15% of total industrial energy use for the U.S. They put the annual national non-process energy use between 1.25 quadrillion Btu (qBtu) and 4.2 qBtu. They also estimate that 84% of the non-process energy was used for space heating, 8% for air conditioning and 8% for lighting.

For the overall manufacturing sector, the IEUDB gives a figure of 1% (in 1974) for fraction of purchased energy used for space conditioning and lighting. We suspect that some portion of building services are included in the "non-specified energy uses" category. According to IEUDB, 17% of purchased electricity in 1972 in manufacturing was used for building services.

In the EADC program, one-third of all realized cost savings resulted from measures that applied to the building services sector. The EADC study did not cover California, but if the findings are any guide to conditions of industrial facilities within California, the types of conservation measures recommended in the report would have reduced energy use by 11.5% and reduced costs by 10%.

According to ERC's study for California [8], 15.3% of the energy purchased was used for non-process purposes: 17% of this went for lighting, 31% for air conditioning, and 52% for space heating. BAH[2] reported that, based on the PG&E EUA data, space cooling was the largest end use in the semiconductor industry and the computer industry. For the semiconductor industry, air conditioning used 39.2% and lighting used 12.4% of the energy purchased. Similar figures for the computer industry were 36.4% and 26.7% for lighting. These figures indicate the importance of non-process energy use for these sectors, which are also very important to California.

Based on our study of the PG&E EUA for five selected industries, the contribution of total electricity consumption for lighting ranges from 9.5% in frozen fruits to 29.1% in instruments; total electricity consumed by air conditioning, ranges from nonexistent in frozen fruits to 35% in instrument manufacturing. None of the five industries selected had significant electrical space heating. Gas space heating consumption ranges form 5% in the motor vehicles facilities to more than 58% in the instrument manufacturing industry.

It is clear that, especially in California, energy used for building services is a substantial part of the total energy use. In-depth case studies including measurements and simulations would give an idea how accurate the audit questionnaire results are and insight into possible data gaps or methodological lacunae that have led to inconsistencies in the audit data collected to date. We believe the utilities should extend and enhance their methodologies for collecting data in the light of the findings of such studies. Eventually, the audit results by different organizations may be integrated to form a common database for California and be made available to researchers, practitioners, and utilities.

We also believe that demonstration of conservation and load-shaping measures is a proven method to encourage energy efficiency in California industries.

The University-wide Energy Research Group (UERG) and the Lawrence Berkeley Laboratory (LBL) jointly sponsored a one-day workshop in November 1988. The workshop focused attention on energy use in industrial buildings. The results, presentations and discussions among the attending parties are documented [15]. The workshop highlighted the need to improve our understanding of this neglected sector of energy use.

Energy efficiency in industry and the potential of conservation and load-shaping opportunities justifies a collaborative research program in this area by CIEE, CEC, and California utilities. Other utilities on the west coast like Seattle City Light may also be interested in such collaboration.

References

1. Marc Ross, "Industrial Energy Consumption," Natural Resources Journal, V. 24, p. 369 (April, 1984)
2. Booz, Allen and Hamilton Inc., Economics and Forecasting Department, Industrial Sector Market Study Report to Pacific Gas and Electric (PG&E), February 26, 1986.
3. EPRI report EPRI-EA-4338, "Electric Utility Market Research Symposium," published by Synergic Resources Corporation, November 1985.
4. Synergic Resources Corporation, on contract from Bonneville Power Administration and North Carolina Alternative Energy Corporation, "Survey of Industrial Conservation and Co-Generation Potential in the Pacific Northwest," March 1985.
5. WESTAT, "Nonresidential Buildings Energy Consumption Survey," Report DOE/EIA-0318/1 to Department of Energy, (1982).
6. Oak Ridge Associated Universities "Industrial Energy Use Data Book," Report No. ORAU-160, (1980).
7. Hagler Bailly and Company, "Industrial Buildings Energy Use," HBC reference number 87-3025. Prepared for DOE Office of Buildings and Community Systems, Released March 31, 1987.
8. Energy and Resources Consultants Inc., "A Characterization of Energy Use in Selected California Industries," Report submitted to California Energy Commission, April 1983. (ERC, P.O. Drawer 0, Boulder CO 80306. Phone (303) 449-5515).
9. Pacific Gas and Electric, "Industrial Audit Reports," Reports of Energy Utilization Audit (EUA) from PG&E, made available to us on magnetic tape by Mr. W. Idzerda of PG&E.
10. EADC (Perrotti, G.M., Johnson, J.H., and Kirsh, F.W.), "Energy Conserved and Cost Saved by Small and Medium size Manufacturers," Report for program period 1984-85. Published for DOE by University City Science Center - Center for Energy Management and Industrial Technology January 1987, Philadelphia PA. Phone (215) 387-2255.
11. ASHRAE, "Data from Facilities Winning the ASHRAE Awards for Energy Conservation."
12. McDonald, J.M., et al, "Commercial Sector Characterization," Draft Report. "Commercial Energy Retrofit Research - Preliminary Sector Characterization," Oak Ridge National Laboratory.
13. Dun and Bradstreet, "Major Industrial Plant Database."
14. Trinet Corporation, "Annual Survey of U.S. Industrial and Commercial Building Power," Trinet Corporation, Campus Drive, Parsippany NJ 07054, 201-267-3600.
15. Akbari, H. and Gadgil, A. (1989), "Workshop Proceedings of the Industrial Building Energy Use," Lawrence Berkeley Laboratory Report LBL-27658.

Appendices

Appendix 1
Non-Residential Building Energy Consumption Survey (NBECS)

The Nonresidential Buildings Energy Consumption Survey (NBECS) [5], was conducted by WESTAT for the Department of Energy. Although the surveyors intended to analyze commercial buildings, 620 industrial buildings (11% of the total surveyed) were, by mistake, industrial. The NBECS information was gathered by interviewing building managers and owners. We analyzed the data on these 620 buildings to first identify and then examine those located in California. Anonymity of facilities included in the survey was assured by WESTAT. However, very approximate location of each building (by region) is published. California belongs to what is called census region number 4. This region encompasses the eleven states of WA, OR, CA, ID, MT, WY, CO, UT, AZ, NM, and NV. Each building could localized more specifically than in the report by comparing the reported annual heating and cooling degree days to those found in California climates. The major population centers of California lie within climates with fewer than 2,000 cooling degree days and than 4,000 heating degree days, all based on 65 °F. (The less populated regions of far northern California and the higher elevations of the Sierra Nevada are outside this range). These climate characteristics extend into small sections of NV, AZ, and NM, but upon close examination of these regions, we see that they do not include any major population centers. Even if a few of the buildings we identified are outside of California, the effects of climate on their energy use should be comparable to those on the buildings in the populous regions of CA with similar climates. One other possible identifying characteristic associated with each surveyed building is the unit price of electricity and gas. Since the major utilities in CA have different rates, it may be possible to associate reported energy prices with a particular utility's rate schedule and thereby narrow the location of each building to within a particular service area. This was not a purpose of study, but knowledge of climatic factors may help us understand energy use for these buildings.

Applying the selective criteria of census region and climate, we selected 39 buildings from the original subset of approximately 620. Of these, two housed leather, textile or both activities, 11 were classed as light assembly, three as heavy assembly, two as paper, chemicals, or rubber or some combination, five as metal working, glass fabrication or both, two as printing and/or publishing, one as storage-retail, and four as storage-manufacturing of non-food. The remaining nine buildings were not identified by the nature of their industrial activity. The data on these 39 buildings were examined. NBECS building data are not classified by SIC; thus, there is ambiguity regarding details of the industrial activity within these buildings. For example, the floor area reported for each building included indoor parking facilities and basements—thus a truck loading dock (which may or may not be conditioned) could lead to an erroneous value for the intensity of energy use calculated. In the summary of findings in the NBECS report [5] the authors remark that the industrial buildings surveyed were excluded from the section on consumption and expenditure because the sample was too small to be representative and the energy consumption estimates varied widely within the sample.

Attempts to discover energy end uses and magnitudes directly by an examination of the data base showed that much useful information was missing. To clarify this point by illustration, we reproduce below several questions asked by the interviewer:

Concerning the use of electricity (question 54):
"What kind of cooling system(s) supply the air conditioning for this building?
Pick the one choice that most nearly describes the air-conditioning system here.

a. Window units only

b. One or more packaged units--i.e., built and assembled at a factory and installed as a unit at the building

c. A simple central system which serves all areas of the building that are air conditioned and which was specially constructed for this building

d. Something else or any combination of the above (specify)."

Another example (question 71), concerning the use of other sources:
"Are there any boilers in the building?
yes____ no___ don't know ___."

This information would have been vastly more helpful if only the number of units with their cooling capacity or heating capacity were recorded. The survey questionnaire contained numerous omissions of this type, which makes meaningful analysis of end uses impossible. This limitation has also hindered other researchers. MacDonald et al. attempted to use the NBECS data to estimate energy end use in commercial buildings that do not have industrial processes [12]. They noted at the beginning of their report: "A major limitation to the NBECS data is the lack of information necessary to prorate the total energy consumption among the specific types of energy using equipment (i.e., no submetered data)." They also stated, "The level of detail available for NBECS survey for HVAC systems is noticeably lacking for lighting systems, the other major energy user, and is especially limiting when considering the lack of knowledge of existing daylighting potential and interactions with HVAC system demands. Plans for the next survey (1986/87) were intended to rectify this situation..."

Nonetheless, an attempt was made to discover some pertinent information on non-process energy end use in the 39 industrial buildings identified earlier as probably located in CA. Electricity consumption was examined to see if there would be correlations between electricity use, number of workers, hours of operation, unit cost of electricity, and other variables. Table A.1 shows ratios that would ordinarily be expected to lie in a narrow range of values for a given type of building use.

No pattern is identifiable. For example, consider SIC classification 73, light assembly. The average demand per square foot (usually called the intensity of energy use) during hours of operation, given in column 12, varies from 0.07 to 12.05 watt/ft^2. This represents variation by a factor of 170. A similar situation for gas consumption is seen in Table A.2.

In the classification of heavy assembly(74), one sees in column 8, natural gas consumption intensity, in Btu/(hour·ft^2), ranges from 0.85 to 75.93, differing by a factor of almost 90. Two of the plants are approximately the same size, 61,576 vs. 56,563 ft^2, and both employ 175 workers, with one operating 26 more hours per week than the other. If the total annual energy consumption (electricity, gas, fuel oil, and liquid gas) is summed and divided by the floor area and annual hours of operation, some consistency is expected in the resulting numbers within a given industrial classification. The following ranges and averages (Table A.3) were obtained for CA climate buildings in total Btu/(ft^2·hour).

Table A.1

Summary of NBECS 1979 Industrial Building Electricity Energy Use Characteristics in California

Building classification*	Floor area, ft^2	Number of workers	Hours of operation per week	Electric consumption, MMBtu/yr.	Cost of electricity in $/MMBtu	Electricity in $KBtu/ft^2$	Electricity in Btu/(hr operation. ft^2)	Annual electricity consumption in (MMBtu/worker)	Electricity in Btu/(hr. ft^2 worker)	Cost of electricity in ¢/(hr worker)	Average demand (watt hr)/(ft^2 hr. operation)	Demand based on 8760 hr/yr (watt hr)/(ft^2 hr)
700	331819	4	168	7149	9.8	215.45	24.66	179	.06	20.06	7.23	7.21
700	2499	275	168	2257	9.51	90.31	10.34	82	.04	8.93	3.03	3.02
700	2030	1	4	74	20.21	36.51	17.55	74	17.55	72.02	5.14	1.22
700	5498	1	85	77	17.43	14.17	3.21	8	.32	3.07	.94	.47
700	12112	2	5	146	18.94	12.06	4.64	7	.23	5.32	1.36	.4
700	637	4	12	470	13.52	73.91	11.85	11	.3	2.55	3.47	2.47
700	3254	17	4	8	19.28	24.76	11.91	5	.7	4.39	3.49	.83
700	54889	5	5	7799	7.44	142.08	54.65	156	1.09	44.66	16.02	4.75
700	1013	5	4	61	10.57	60.72	29.19	12	5.84	6.25	8.56	2.03
720	26287	75	95	456	18.53	17.37	3.52	6	.05	2.28	1.03	.58
720	248686	35	152	46183	11.02	185.71	23.5	132	.07	18.39	6.89	6.21
730	98	25	4	6854	10.98	69.93	33.62	27	.01	14.47	9.85	2.34
730	392	2	44	15	26.94	4.03	1.76	8	.88	9.31	.52	.13
730	35496	55	56	262	19.11	7.38	2.54	5	.05	3.13	.74	.25
730	1617	15	93	819	18.76	50.68	10.48	55	.7	21.2	3.07	1.7
730	19584	15	4	131	18.35	6.71	3.23	9	.22	7.74	.95	.22
730	27279	2	4	2332	15.87	85.51	41.11	117	2.06	89.00	12.05	2.86
730	20112	15	4	103	16.86	5.13	2.47	7	.16	5.58	.72	.17
730	21146	3	4	332	15.35	15.72	7.56	11	.25	8.18	2.22	.53
730	98813	18	85	103	14.76	1.04	.24	57	.00	.19	.07	.03
730	73778	22	55	717	13.54	9.72	3.4	3	.02	1.54	1.00	.33
730	25483	85	62	489	12.68	13	5.96	6	.07	2.26	1.75	.64
740	245	62	76	129	14.79	52.72	13.34	21	.22	7.8	3.91	1.76
740	61576	175	76	20570	9.56	334.06	84.53	118	.48	28.43	24.77	11.18
740	56563	175	5	5119	12.12	90.5	34.81	29	.2	13.64	1.2	3.3
750	867	12	4	228	18.31	13.61	19	1.13	16.75	3.99	.95	
750	1764	27	12	3	11.75	27.30	111	1.01	20.90	8	5.7	
760	6726	14	55	110	18.7	16.41	5.74	8	.41	5.16	1.68	.55
760	2966	6	5	371	17.99	125.23	48.17	62	8.03	42.83	14.12	4.19
760	26287	65	8	2151	13.76	81.84	19.67	33	.3	10.95	5.77	2.74
760	8119	7	4	102	22.57	12.66	6.09	15	.87	15.95	1.79	.42
760	7407	75	5	1554	14.81	209.82	80.7	21	1.08	11.81	23.65	7.02
770	2022	5	4	1	97.37	.51	.25	21	.05	.97	.07	.02
770	141	6	55	1370	10.62	97.13	33.96	23	.57	8.48	9.95	3.25
1044	24694	15	45	1921	13.91	77.81	33.26	128	2.22	76.16	9.75	2.6
1044	53456	7	45	54	22.37	1.02	.44	78	.01	.75	.13	.03
1044	118687	85	5	451	13.03	38.0	14.62	53	.17	26.6	4.28	1.27
1044	2733964	15	12	372	17.28	13.6	2.18	25	.00	6.87	.64	.46
1044	9905	62	6	126	14.68	12.73	4.08	2	.07	.96	1.2	.43

700=Industrial 720=Leather, textile 730=Light assembly 740=Heavy assembly 750=Paper, chemicals, rubber 760=Metals, glass 770= Printing, publishing 1040=Warehouse 1044=Storage, manufacturing, nonfood

Table A.2

Summary of NBECS-1979 Industrial Bldg. Gas Energy Use Characteristics in California

Building classification	Floor area, ft^2	Number of workers	Hours of operations per week	Natural gas consumption, MMBtu/hr.	Cost of natural gas in $/MMBtu	Gas consumption in $KBtu/ft^2$	Average gas demand Btu/(hr. ft^2)	Annual gas consumption per worker (MMBtu/worker)	Gas consumption in Btu/(hr. ft^2 workers)	Cost of gas in ¢/(hr. operation workers)	Gas consumption based on 8760hr/yr Btu/($ft.^2$ hr)
700	331819	4	168	161443	2.71	486.54	55.69	404	.14	12.5	55.54
700	2499	275	168	121115	2.68	484.65	55.48	440	.2	13.51	55.33
700	2030	1	4	12	7.18	6.17	2.97	12	2.97	4.33	.70
700	5498	1	85	55	2.90	10.04	2.27	5	.23	.36	1.15
700	12112	2	5	32	2.64	26.43	10.17	16	.51	1.63	3.02
700	637	4	12	0	.	.	.	.	.	.	.
700	3254	17	4	58	3.49	178.49	85.81	34	5.05	5.74	20.38
700	54889	5	5	6763	2.48	123.21	47.39	135	.95	12.92	14.07
700	1013	5	4	0	.	.	.	.	.	.	.
720	26287	75	95	156	2.86	5.94	1.2	2	.02	.12	.68
720	248686	35	152	11738	2.42	47.2	5.97	33	.02	1.03	5.39
730	98	25	4	5081	2.28	51.85	24.93	20	.01	2.23	5.92
730	392	2	44	0	.	.	.	.	.	.	.
730	35496	55	56	2096	2.58	59.07	20.29	38	.37	3.38	6.74
730	1617	15	93	77	3.24	4.76	.99	5	.07	.34	.54
730	19584	15	4	257	2.74	13.15	6.33	17	.42	2.26	1.5
730	27279	2	4	0	.	.	.	.	.	.	.
730	20112	15	4	0	.	.	.	.	.	.	.
730	21146	3	4	195	2.67	9.22	4.44	6	.15	.84	1.05
730	98813	18	85	15474	2.82	156.6	35.43	85	.2	5.49	17.88
730	73778	22	55	2265	2.84	30.71	10.74	10	.05	1.02	3.51
730	25483	85	62	817	2.75	32.07	9.95	9	.12	.82	3.66
740	245	62	76	581	2.62	23.72	6.00	9	.10	.62	2.71
740	61576	175	76	18478	2.58	300.08	75.93	106	.43	-6.89	34.26
740	56563	175	5	125	2.87	2.21	.85	1	.00	.08	.25
750	8067	12	4	575	2.96	71.29	34.27	47	2.86	6.83	8.14
750	1764	27	12	424	2.88	2403.80	385.22	1570	14.27	72.56	274.41
760	6726	14	55	368	2.56	54.81	19.17	26	1.37	2.36	6.26
760	2966	6	5	58	3.63	19.71	7.58	9	1.26	1.36	2.25
760	26287	65	8	1323	2.44	50.35	12.10	20	.19	1.19	5.75
760	8119	7	4	0	.	.	.	.	.	.	.
760	7407	75	5	1798	2.44	242.84	93.4	23	1.25	2.25	27.72
770	2022	5	4	51	3.48	25.61	12.31	10	2.46	1.73	2.92
770	141	6	55	359	2.44	25.45	8.9	6	.15	.51	2.91
1044	24694	15	45	0	.	.	.	.	.	.	.
1044	53456	7	45	61	3.53	1.14	.49	1	.01	.13	.13
1044	118687	85	5	6992	2.46	58.91	22.66	82	.27	7.79	6.73
1044	2733964	15	12	64347	2.65	23.53	3.77	43	.00	1.83	2.69
1044	9905	62	6	988	2.83	99.84	32	16	.52	1.45	11.4

700=Industrial 720=Leather, textile 730=Light assembly 740=Heavy assembly 750=Paper, chemicals, rubber 760=Metals, glass 770= Printing, publishing 1040=Warehouse 1044=Storage, manufacturing, nonfood

Table A.3

Averages and Ranges of Total Site Energy Demand Reported Within NBECS Industrial Categories

		Total(Btu/hr)/ft^2				
Category	Sample Size	Low	High	Average	Median	(High/Low)
Industrial	9	5.5	102.0	48.0	53.8	18.6
Leather, Textile	2	4.7	84.9	44.8	44.8	18.0
Light Assembly	11	1.8	96.2	24.3	49.0	54.6
Heavy Assembly	3	19.4	160.5	71.8	89.9	8.3
Paper, Chemicals, Rubber	2	47.9	412.5	230.2	230.2	8.6
Metal, Glass	5	6.1	174.1	58.5	90.1	28.6
Printing, Publishing	2	12.6	42.9	27.7	27.7	3.4
Mfg. of non-food, Storage	4	0.9	37.3	20.5	19.1	41.2

The widely spread values indicate several possibilities: 1) the data base may be flawed, 2) the technology used in process or the building services varies widely within the same industry, which would make it appear that there are many energy efficient measures which could be implemented, or 3) the data base does not delineate the industrial processes in adequate detail to justify or explain these differences.

Another possibility is that industrial buildings may have widely varying service requirements because of the nature of the activity they house. Using data showing identical climate, one may seek a relation between the percent of the facility which is cooled and the average electricity demand during operating hours, watts/ft^2. To establish such a relationship is difficult as seen from Table A.4.

The reported data are inadequate for estimating the power used for cooling. The same applies for the data correlating the consumption of natural gas, fuel oil, and liquid gas use with heating degree days and percent of the facility which is heated. In summary, after a careful examination, NBECS data only reinforce the assertion that there is a lack of reliable data on industrial buildings including the extent and manner in which energy is used for non-process needs.

Appendix 2
Hagler, Bailly & Co.

In a report to DOE, Hagler, Bailly & Co.(HBC) [7] note that the opportunities for improving industrial buildings' energy efficiency have remained largely untapped. The research team that wrote the report addressed five tasks:

1. carrying out a literature review,
2. investigating industrial buildings' non-process energy conservation by contacting 37 experts who were corporate energy managers; associates of professional groups and societies, governmental agencies, laboratories, vendors; or associates of design and construction firms,
3. segmenting the industrial buildings sector by major SIC groups and characterizing non-process energy use in each segment; focusing on industries which require significant degree of environmental control, and omitting industries such as cement and steel-making,
4. assessing residential and commercial conservation measures' appropriateness for industrial buildings, and
5. estimating the savings that could be realized if conservation measures were adopted.

Segmentation of industrial categories was by two-digit SIC. The study excluded industries in which most activity is out of doors. Information on non-process energy use was collected for each industry segment by

1) Discussion with industry representatives responsible for energy management,
2) Detailed audits performed by Hagler, Bailly since 1980, and
3) Available literature and studies on non-process industry energy use.

Non-process energy use was disaggregated into 1) Space Heating, 2) Ventilation air conditioning, and 3) Lighting.

Variations in space heating and cooling requirements by geographic locations were estimated. Estimates for space heating were based on total fossil fuel use. The report notes that the majority of medium and large industrial facilities use fossil fuel driven boilers or furnaces; only a small percentage use electric space heating. Estimates of ventilation, cooling, and lighting are based on electricity consumption.

For estimates of space heating, the heating degree days, numbers of production employees, and electric-to-fossil ratio were correlated with 1984 reported space heating consumption tabulated in the Dun & Bradstreet Major Industrial Plant Database [14], which details the process and plant energy use of more than 21,000 industrial facilities nationwide, accounting for an estimated 90% of total U.S. industrial energy use. These estimates were preferred over several other sources of estimated data because the other sources often have incomplete coverage of industrial segments, and contain outdated and/or inconsistent data (e.g. several published sources report significantly different energy consumption figures for the same industry during the same time period).

Table A.4

Percent of the Facility which is Cooled and the Average Electricity Demand During Operating Hours as reported by NBECS-1979

Building Classification	Average Demand w/ft^2	Percent Cooled %	Cooling Degree Days Base 65 °F
Industrial	7.23	5	221
"	3.03	2	221
"	5.14	100	813
"	.94	0	813
"	1.36	10	812
"	3.47	5	812
"	3.49	100	813
"	16.02	25	813
"	8.56	100	2233
Textile, Leather	1.03	0	813
"	6.89	60	812
Light Assembly	9.85	50	812
"	.52	0	813
"	.74	15	813
"	3.07	25	813
"	.95	8	813
"	12.05	5	813
"	.72	10	813
"	2.22	30	813
"	.07	5	221
"	1.00	0	221
"	1.75	0	221
Heavy Assembly	3.91	100	813
"	24.71	80	813
"	10.20	15	813
Paper, Chem., Rubber	3.99	62	813
"	8.00	10	221
Metal, glass	1.68	20	
"	14.12	100	813
"	5.77	100	813
"	1.79	0	813
"	23.65	10	813
Printing, Publishing	.07	0	813
"	9.95	100	2233
Storage	9.75	60	813
Storage, non-food mfg.	.13	5	813
"	4.28	10	813
"	.64	1	221
"	1.20	0	221

In exhibit 2.c of their report, HBC tabulate average percentage of estimated fossil fuel used in 1985 for space heating by two-digit SIC. We used appendix F of their report to obtain very approximate values of California space heating percentages for comparison. Exhibit 2.d of the report displays the DOE regional use of space heating fuel types. Ventilating and air-conditioning (VAC) estimates were based on a plant's total electric energy consumption in much the same way as heating estimates were based on total fuel consumption (exhibit 2.f). We used appendix G of HBC's report to estimate the average percentage of total electricity consumption attributed to cooling in California industries. According to these estimates, California use differs little from national averages. The percentage contribution of VAC to total electricity use differs significantly from space heating contribution to total fuel use because not all industrial facilities require air conditioning, and the total plant consumption of electrical energy can be high; thus, the percentage contribution of VAC to total electrical demand can be small. As expected, electronics manufacturing (SIC 36) requires a large amount of ventilating and air conditioning. However, the largest users of VAC energy appear to be the chemicals (14.6 TBtu/yr(10^{12}Btu/yr)), machinery (17.8 TBtu/yr), electrical and electronics (19.6 TBtu/yr), and transportation (13.1 TBtu/yr) industries.

Energy consumption for lighting of industrial plants varies in intensity (watts/ft^2) and also when expressed as a percentage of electrical demand. Estimates were based on Illuminating Engineering Society guidelines, which range from 0.6 to 6.8 watts/ft^2 based on task. Variations in the percentage of electricity used for lighting in similar industries was assumed not to be a function of geography. The lighting energy as a percent of total electrical consumption is given for each two-digit SIC code in exhibit 2.i of the HBC report. California use, on average, is estimated to be the same as national.

The HBC report points out that, nationwide, the transportation industry (SIC 37) uses the most non-process energy, about 173 TBtu/yr or about 14% of all industrial non-process energy use. The next three largest users, in order, are reported to be the non-electric machinery (SIC 35), food (SIC 20), and chemical (SIC 28) industries, as shown in exhibit 2.j of the HBC report.

Findings of HBC

Information obtained from industry representatives and literature review shows nearly all surveyed companies have instituted some energy conservation measures since 1980. Approximately 5% savings were realized from good housekeeping and maintenance procedures. Lighting received considerable attention; the most common measure was relamping with high pressure sodium fixtures. HBC also found that most larger companies have an energy management program. A few programs are quite extensive, including training of employees on how to optimize equipment operation. Many smaller companies, for example, with annual sales less than $50 million, show little or no energy management effort and tend to be unaware of the extent of non-process energy use. Several other companies looked exclusively at process uses but had not explored the magnitude and conservation potentials of non-process use. Smaller firms in general demonstrated less awareness of non-process energy conservation. The Association of Energy Engineers (AEE) reports recently that, because of cheaper energy prices "industrial clients are not as interested in energy conservation as they once were ..." Efforts to reduce electricity consumption continue because electricity prices have not dropped. According to AEE, more than 60% of the commercial and industrial firms they surveyed reported having energy management systems, which had average payback periods of two to three years. Industries like food, paper, rubber, and glass have concentrated on process energy use, which accounts for perhaps 95% of their energy consumption. Textiles, chemicals, and electrical industries have made moderate efforts to improve non-process use because temperature and humidity may affect product. Engineering firms believe that automotive and machinery manufacturing industries could benefit greatly from non-process energy conservation efforts because most buildings require fixed ventilation, and substantial lighting and winter heating. Smaller operations may not have time or support from management to evaluate building energy conservation even though many cost-effective measures may exist. Also, perhaps basic information is not reaching these firms. Discussions with industrial staff indicate much uncertainty and lack of knowledge could be eliminated through a systematic program of research, development, and demonstration directed at improving the efficiency and performance of non-process use. The HBC report suggests that a federally supported program should develop information on cost-effective energy conservation opportunities for retrofitting existing industrial buildings, and advanced designs and equipment for new industrial buildings. Support for these efforts could come from joint sponsorship with industry. No one, to date, is taking a leading role in sponsoring and demonstrating efficient use of non-process energy in industrial buildings.

Potential for Energy Conservation in Industrial Buildings

The HBC report concludes that industry has given scant attention to energy conservation in lighting, heating, and cooling. The building industry conducts only limited research for non-process energy use in industrial buildings; it relies instead on the research by component suppliers. As a result, adoption of energy-efficient building technologies gets delayed owing to lack of research funding from private and public sources. The Office of Buildings and Community Systems (OBCS) of DOE concentrates on residential and commercial buildings whereas the Office of Industrial Programs (OIP) focuses on process equipment. Many of the recent advances in design and operation of industrial buildings are adaptations of technologies developed for the commercial sector. While this is encouraging in the absence of any direct research funds, better technologies may be possible if intentionally developed for industrial buildings. Industrial non-process energy use is estimated to be 1.2 quadrillion Btu (qBtu) per year. The HBC report states that "Total savings of 15-20% are conservatively estimated to be achievable from retrofit improvements in building systems." These estimates of potential energy savings are "based on results of research on related technologies, on the savings achieved by similar programs in the commercial buildings sector, and on information obtained from discussions and relevant literature."

The HBC report identifies the following categories of R&D opportunities for industrial buildings:

A) Building Envelope

B) HVAC Systems & Controls

C) Building Systems Integration

D) Lighting

E) Technology Transfer

A) Building Envelope

The authors of the HBC report had discussions with representatives of *Plant Engineering Magazine*, who indicated that improvements to building envelopes (e.g., materials, construction methods, minimized infiltration) are currently high-priority topics in U.S. industry. Since many industrial buildings are steel beam and metal siding, and often uninsulated, the HBC report estimates minimum achievable energy savings of 5-8% of national non-process energy use.

B) HVAC Systems and Controls.

The HBC report estimates that sensors and controls [Energy Management Systems(EMS)] could decrease HVAC energy use by approximately 20%. Developing and encouraging use of EMSs could result in savings conservatively approaching 10% of total industrial HVAC energy use. The staff at nearly 25% of the companies HBC contacted reported that instead of the 15-25% savings claimed by the manufacturers of EMS, only 8-10% savings were observed. Some industrial plant managers consider EMSs to be nothing more than expensive time-clocks.

C) Buildings Systems Integration

This concept involves understanding the interaction of the building envelope, HVAC, lighting and process loads by building zone and determining optimum combinations of equipment and operating strategies that provide the best energy efficiency. Innovative methods of integrating industrial building energy systems need to be developed.

The magnitude of achievable energy savings from building systems integration is difficult to estimate but can be substantial. An example is the 35% savings in energy and $ 1 million savings in initial equipment cost at one of Monsanto Company's research facilities through partial integration of its HVAC systems. Estimates of savings from similar actions implemented nationally exceed 15% of total industrial non-process energy consumption.

System integration, stratification reduction, elimination of overdesign (as for some with clean rooms), and using more cost-effective heat recovery methods are some ways to reduce non-process industrial energy use without compromising the service provided.

D) Lighting

Despite improvements incorporated by industry, such as de-lamping and re-lamping with more efficient fixtures, much more could be accomplished. Daylighting opportunities frequently are ignored or overlooked. Although the American Institute of Architects (AIA) along with the Association of Professional Energy Managers indicate that the potential for daylighting in industrial buildings is "good," little information and few technologies exist for the industrial sector. Some high-efficiency light sources cannot be used because they have poor color rendition. Serious accidents and mistakes in color coding have resulted from inappropriate use of sodium lighting. More research on the safety issues of this lighting is needed. Cost and performance data on dimming systems seem to be lacking. The authors of the HBC report estimate that lighting in industrial buildings typically constitutes about 10% of total plant electrical load. No potential savings estimates were given.

E) Technology Transfer

The adoption of energy conserving technologies by industry has been hampered because many of the potential users are small- and medium-size companies. Their lack of extensive networking and interaction with professional and trade organizations results in skepticism about performance of "unproven" technologies, and lack of current knowledge. The Association of

Energy Engineers (AEE) staff expressed their amazement to the HBC team regarding the lack of knowledge in industry concerning various energy conservation methods.

The HBC report suggests the following activities and procedures to overcome these problems:

- Determine needs of end users and most effective ways to communicate with end users.
- Develop research briefs, fact sheets, and technical articles.
- Conduct seminars, conferences, round tables, and dialogues to present new technologies and applications.
- Assess effectiveness of efforts through feedback from end users.

Technology transfer of international developments is also needed because energy efficient technology (such as radiant floor slabs, and modular prefabricated industrial building construction) have been used for many years in other countries.

HBC Conclusions and Recommendations

HBC estimated that closed industrial building non-process energy use was approximately 15% of total industrial energy use. This estimate was based on the Dun & Bradstreet Major Industrial Plant Database (MIPD) [13], which gives a total annual industrial energy use of 9.6 qBtu and non-process energy use of 1.25 qBtu. Other sources, such as Energy Information Administration (EIA), estimate total industrial energy use to be between 21 and 28 qBtu, which would place an upper limit of about 4.2 qBtu on non-process use.

Approximately 84% of non-process energy used by industrial buildings nationwide was for space heating. Air-conditioning/ventilation, and lighting divide the remainder equally. Discussion with industry and research organizations indicate that 20% of non-process energy use could be conserved.

The authors of the HBC report urge DOE's Office of Buildings and Community Systems to become as involved with industrial non-process uses of energy as they are with the commercial and residential. The HBC team considers prime candidates for attention to be the electric and non-electric machinery and transportation industries (SIC 35-37), the food industry (SIC 20), and the chemical industry (SIC 28) because of the large amounts of non-process energy use in these sectors.

Appendix 3

Energy Analysis and Diagnostic Centers (EADC)

This report summarizes of energy conserved and costs saved by small and medium-sized manufacturers during the 1984-85 EADC Program Period; it was published in January 1987 [10]. Ten centers (EADCs) recommended 2,168 energy conservation measures to 296 small and medium-sized manufacturers located in 24 states other than California over a 12-month period ending September 30, 1985. Recommendations were presented to manufacturers individually after on-site analyses of their plants. These companies, representing 18 different industries, showed potential savings of about $10 million/year (roughly 10% of the plants' total energy costs), or 1.63 trillion Btu/year (about 11.5% of their total energy use). Approximately 3/4 of the identified energy conservation potential was in process use, accounting for about 2/3 of the identified dollar savings of 1984-1985.

Since its inception, EADCs have helped 1,456 manufacturers and identified more than $50 million/year in cost savings and 10 TBtu/year in energy conservation for their facilities. During the 1984-85 reporting period the leading source of energy conserved was natural gas, amounting to 46% of the total. Because of its higher unit price, electricity was the leading energy source for dollars saved, 44% of the total.

The largest amounts of realized energy savings from EADC efforts were in the lumber and wood products industry, SIC 24; the second highest were in textile mills, SIC 22; followed by food products, SIC 20; then by fabricated metals, SIC 34. These four industries accounted for more than 57% of the total conservation identified.

The largest cost savings were realized in textile mills, SIC 22; next largest savings were in food products, SIC 20; followed by chemicals, SIC 28; then by fabricated metals, SIC 34; primary metals, SIC 33; and rubber and plastics, SIC 30. The savings both in energy and cost per plant were markedly different among industrial categories. The average energy conservation per plant for each of the top three categories was: 27,208 million Btu for SIC 24, 12,860 million Btu for SIC 22, and 11,000 million Btu for SIC 32. The three categories with the lowest energy savings per plant were SIC 38 with 1,710 million Btu, SIC 27 with 1,329 million Btu, and SIC 31 with 1,100 million Btu. The top three categories in average dollar savings per plant were SIC 22 with $84,000, SIC 28 with $54,700, and SIC 31 with $49,000. The lowest three categories in average dollar savings per plant were SIC 38 with $18,800, SIC 25 with $19,600, and SIC 27 with $26,700.

Industries such as chemicals, cement, or paper with several high-temperature operations or with large throughputs are likely to have large energy savings opportunities. Large savings in cost are usually possible in industries with a lot of electrically driven equipment or industries that could switch to lower priced energy sources.

EADC-served industries were able to conserve large amounts of energy in three categories: combustion, process-equipment, and buildings and grounds. Taken together these three categories accounted for more than 80% of energy conservation and nearly 70% of cost savings. The major recommended energy conservation measures in the category of buildings and grounds amounted to about 20% of the energy conservation potential and 27% of the cost savings potential. Conservation in combustion and process equipment, and conservation by process changes made up 68% and 41% of the recommended energy and cost savings potentials, respectively.

Implemented conservation measures in the buildings and grounds category amounted to 26% of the energy conserved and 31% of the cost saved, whereas conservation measures implemented combustion and process equipment and process changes accounted for 55% of the energy savings and 37% of the cost savings. Although 3/4 of the potential energy conservation was identified in process use, only 55% of the implemented measures occurred in process. These percentages seem to indicate that management is more likely to implement changes in equipment and procedures that do not directly involve the plant process itself.

Of the three major groups accounting for the most implementation, combustion had the largest conservation potential and yielded the largest energy savings. The buildings and grounds group showed the largest dollar savings in both recommended and implemented categories. Space heating and cooling measures were implemented almost as often as lighting recommendations and saved about 1.8 times as much money. Most of the principal energy-conservation measures implemented can be classified as good operating procedure. The conservation measures most frequently implemented are listed below:

1. Adjust burners for optimal air/fuel ratio.
2. Install timers and/or thermostats for heating and air conditioning.
3. Monitor boiler efficiency and improve control capability.
4. Use waste heat from hot flue gases to preheat combustion air.
5. Install, upgrade, or repair insulation on steam lines.
6. Repair and eliminate leaks in steam lines and valves.

To view the relative importance of these conservation measures, as fundamental as they seem, an accounting of these six measures for the 1984-85 EADC program period is presented in Table A.5, with the measures appearing in the same order as the list above.

Table A.5

1984-85 EADC Program Period: The Estimated Contribution to Overall Industrial Energy Conservation by Measures Appropriate to the Building Services

Conservation Measure Number	Conservation Implemented Million Btu/yr	% of Total Implemented Conservation	Conservation Recommended Million Btu/yr	% Implemented Recommendations
1	122,400	15.6	361,100	33.9
2	96,800	12.4	113,200	85.6
3	51,200	6.5	221,000	23.2
4	24,200	3.1	42,900	56.4
5	24,100	3.1	29,900	80.6
6	22,100	2.8	27,500	80.2
Totals	340,900	43.6	795,700	42.8
All ECOs	782,100	100.0	1,627,200	48.1

It is interesting to note that adjustment of burners and installation of timers and/or thermostats for heating and air conditioning saved by far the most energy. The buildings and grounds energy conservation measures (number 2) resulted in 12.4% of all implemented conservation savings. Although it is premature to extrapolate similar potential energy conservation for California industries, it is likely that many of the same building services related measures would be comparably attractive for California.

The principal cost-saving energy conservation measures were also in the building services category. Of the top ten dollar-saving measures listed, seven may apply to building services and are listed below.

1. Install timers and/or thermostats for heating and air conditioning.
2. Adjust burners for optimal air/fuel ratio.
3. Use higher efficiency, lower wattage lamps or ballasts in existing fixtures.
4. Install computer system or timed equipment to control HVAC, including automatic shutdown, enthalpy optimization, economizer cycle; use enthalpy control instead of temperature control.
5. Convert to more efficient light sources (e.g. fluorescent for incandescent, and H.I.D. where acceptable).
6. Install, upgrade or repair insulation on steam lines.
7. Use waste heat from hot flue gases to preheat combustion air.

Table A.6 contains the cost savings achieved from building-services related conservation measures in the same sequence as the above list. The installation of timers and/or thermostats for heating and air conditioning ranked first in dollar savings, and adjustment of burners for optimal air/fuel ratio, ranked second.

More than 1/3 of all realized cost savings resulted from measures that apply to building services. (This, however, does not imply that comparable savings could be expected strictly from measures associated only with building services. For example, a boiler may provide process heat to the exclusion of or in addition to building heating needs. Unless the boiler's use is dedicated or its apportionment to the building services sector is known, any conservation savings or dollar savings cannot be automatically credited to improvement of energy use in the building services.) Two other distinctly building-services-related conservation measures found in Table A.6, numbered 4 and 5, were responsible for more than $306,600 savings/year (or 6% of all cost savings) realized largely because of their frequent implementation and the high cost of electricity.

Table A.6

1984-85 EADC Program Period: The Estimated Contribution to Overall Industrial Cost Savings by Measures Appropriate to the Building Services

ECO Number	Annual Cost Savings Implemented $/year	%Total Savings Implemented	Annual Cost Savings Recommended $/year	% Implemented Recommendations
1.	468,800	9.1	560,500	83.6
2.	421,000	8.2	633,100	66.5
3.	288,600	5.6	523,100	55.2
4.	169,500	3.3	222,800	76.1
5.	137,100	2.7	238,700	57.4
6.	118,500	2.3	150,200	78.9
7.	117,500	2.3	213,900	54.9
Total	1,721,000	33.5	2,542,300	67.7
All ECOs	5,134,800	100.00	9,756,100	52.6

If these findings in states outside California are any guide to conditions of industrial facilities within California, a significant amount of energy use could be eliminated cost-effectively by implementing conservation measures in the building services area. Recommended conservation measures would reduce energy use by 11.5% and reduce costs by 10% . Implemented conservation measures (by EADC, outside of California) are estimated to have resulted in 5.5% reduction in energy use and 5.3% reduction in energy costs. It was also noted that measures recommended at some plants in the 1984-85 program were not implemented until 1986 and are thus not included in the analysis. It is not easy to predict the degree to which a similar program in California would be successful, compared to the other 24 states. First, we don't know to what extent the respective utilities that serve these regions engaged in conservation efforts compared to those in California. Second, because of differences in the industrial mix found in California as compared to the eastern portion of the U.S., conservation potentials of California industries may be greater in the building services sector.

Appendix 4

Energy and Resources Consultants, Inc. (ERC)

A four volume study performed by Energy and Resources Consultants, Inc. (ERC) for the California Energy Commission and released in 1983 contains estimates for many of the industrial categories that are expected to use appreciable amounts of energy for building services [8].

The ERC report is intended to be a tool for forecasting energy demand by industry in both use and form. The industries covered by this report include:

1. SICs 201, 202, 204, 205, 207, 208, 209, which are certain segments of Food and Kindred Industries,
2. SIC 22, Textiles,
3. SIC 23, Apparel,
4. SIC 241, Logging,
5. SIC 244 and 245, Miscellaneous Wood Products,
6. SIC 25, Furniture,
7. SIC 264 and 265, Paper Conversion,
8. SIC 27, Printing and Publishing,
9. SIC 28, Chemicals,
10. SIC 295 and 299, Asphalt and Roofing Products,
11. SIC 30, Rubber and Plastics,
12. SIC 31, Leather,
13. SIC 32, Stone, Clay and Glass,
14. SIC 33, Primary Metals,
15. SIC 34, Metal Fabrication,
16. SIC 35 and 36, Machinery,
17. SIC 37, Transportation Equipment,
18. SIC 38, Instruments, and
19. SIC 39, Miscellaneous Manufacturing.

Many of the industries covered by this report use relatively little energy statewide. Most of the major energy using industries, which usually show comparatively negligible non-process use, have been addressed in other work by the CEC. The two major users covered by this report are chemicals and glass. Most of the data cited were originally obtained from the U. S. Census Bureau's Census of Manufacturers (1977); it is therefore dated by more than a decade. Instead of analysis strictly by SIC, ERC aggregated the SICs of interest into 38 groups on the basis of similar perceived patterns of energy use, then further combined them into eight major classes or "supergroups" which were labeled: 1) chemicals, 2) glass, 3) mineral products, 4) metals, 5) materials processing and conversion, 6) electronics, 7) general fabrication and assembly, and 8) food and kindred. Further, depending on the magnitude of energy use, these groups were divided into three priority classes. Class 1, the highest priority, comprised industries that each used more than 10 TBtu in 1977; class 2 members each used between 5 and 10 TBtu, and class 3 members each used less than 5 TBtu.

Groups of the highest priority received the most attention by the authors and also had the most energy use data available. Less information was available for groups of priority 2, and very little for groups of priority 3. The ERC authors comment that "Energy use characterizations for these groups range from reasonably good (in a few cases with good information), to very poor (where no information at all was available), with most groups lying somewhere between these two extremes." The estimates and data are classed as "highly reliable", "moderately reliable", "fairly reliable", or "unreliable". The table below (Table A.7) lists the group, three-digit SIC, class, energy use based on 1977 census data, and the fraction of total energy use that went for building services.

The annual industrial site purchased energy use in California, surveyed by ERC, is 448.3 TBtu. The total California industrial energy use in 1976, according to the Industrial Energy Use Data Book, is 624.7 TBtu; thus, ERC's survey covers approximately 70% of California industrial use. The important sectors omitted from the California food industry in the ERC survey include fruits, vegetables, and frozen specialties. The Industrial Use Data Book (1977) shows that the California food industry purchased 98.5 TBtu; thus, the above coverage by ERC accounts for only about 45% energy use by this industrial sector.

ERC's energy end-use estimates for the categories lighting, air conditioning and ventilation, and space heating are of interest to this study. Also presented from their study is the mix of purchased source fuel for each group. Table A.8 shows lighting, air conditioning and ventilation, and space heating estimates for all groups of interest in the ERC report.

Note that Super Group 2, the glass industry, is not represented. The primary reason for this is that ERC judged the non-process energy use in this supergroup to be negligible in comparison to process energy use. Columns 1 and 2 of the table denote the ERC aggregated groups and their brief descriptions. Columns 3 and 4 present the annual TBtu of purchased electricity used for lighting and the percentage of the total purchased energy this represents for each group. Columns 5 and 6 show the same for air conditioning and ventilation (which was assumed to be electrically driven). All four fuel categories show equivalent information for space heating with the column headed "% Space Htg" giving the percent of total purchased energy used for space heating by each group. The final column shows the percent of total purchased energy used for space heating and all building services by each group.

Table A.7
Annual Energy Use of California Industries.*

Most data are presented as 3 digit SIC with aggregation according to ERC. The class number shows the annual energy use of each SIC or ERC defined group; class 1 members use more than 10 tBtu/yr, class 2 between 5 and 10 tBtu/yr, and class 3 with less than 5 tBtu/yr.

Group	SIC	Description	Class	Energy Use [tBtu/yr]	% Bldg. Srv.
Super Group 1 Chemicals (Total use 62.6 tBtu, 14% of this survey)					
1-1	281	Inorganic, Industrial	1	14.0	
1-2	286	Organic Industrial	1	18.8	
1-3	287	Agricultural	2	9.3	
1-4	282	Plastics and Synthetics	2	5.7	0.7
1-5	283	Drugs	3	2.0	45.
1-6	284	Soaps, detergents, toilet paper	1	4.6	23.
	285	Paints, varnishes, allied products		1.7	
	289	Miscellaneous		6.5	
Super Group 2 Glass (Total use 29.7 tBtu, 6.6% of this survey)					
2-1	321	Flat Glass	3	2.9	
2-2	322	Glass and Glassware	1	20.2	
	323	Glass products from purchased glass		1.7	
2-3	3296	Mineral wool	3	4.9	
Super Group 3 Mineral Products Industries (Total use 32.5 tBtu, 7.5% of this survey)					
3-1	325	Structural Clay Products	1	6.9	0.8
	326	Pottery and related products		3.1	
3-2	327	Concrete, Gypsum, Plaster Products	1	14.3	0.8
3-3	328	Cut Stone, Stone Products	2	0.2	4.7
	329	Misc. Mineral Products		8.0	
Super Group 4 Metals (Total use 57.3 tBtu, 13% of this survey)					
4-1	331	Blast Furnaces, Steel Works, Mills	1	27.5	0.4
4-2	333	Primary Smelting, nonferrous	3	0.1	1.7
	334	Secondary Smelting, nonferrous		3.8	
4-3	332	Iron and Steel Foundries	2	4.1	6.3
	336	Nonferrous Foundries		3.4	
4-4	335	Rolling, Extruding, nonferrous	1	6.2	9.0
	339	Misc. Primary Metal Products		2.4	
	346	Metal Forging, Stamping		5.0	
	347	Coating, Engraving, Allied Services		4.8	

*ERC coverage of 2 digit SIC is not complete for SICs 20,26,29, and 32.

Table A.7(cont.)
Annual Energy Use of California Industries.*

Most data are presented as 3 digit SIC with aggregation according to ERC. The class number shows the annual energy use of each SIC or ERC defined group; class 1 members use more than 10 tBtu/yr, class 2 between 5 and 10 tBtu/yr, and class 3 with less than 5 tBtu/yr.

Group	SIC	Description	Class	Energy Use [tBtu/yr]	% Bldg. Srv.
Super Group 5 Materials Processing and Conversion (Total use 114.8 tBtu, 26% of this survey)					
5-1	220	Textile Mills	2	6.0	19.
5-2	264	Converted Paper and Paperboard	2	2.9	29.
	265	Paperboard Containers and Boxes		4.5	
5-3	295	Paving and Roofing Materials	1	62.0	0.3
	299	Misc. Products of Petroleum and Coal		22.0	
5-4	301	Tires, Inner Tubes	2	4.4	11.
	302,303	Rubber and Plastic Footwear		0.1	
	304,306	Reclaimed Rubber, Hose, Belts		1.7	
5-5	307	Misc. Plastic Products	1	10.3	13.
5-6	310	Leather and Leather Products	3	0.9	16.
Super Group 6 Electronics (Total use 21.0 tBtu, 4.6% of this survey)					
6-1	357	Computers and Office Machines	3	3.5	72.
6-2	365	Radio and TV Receivers	3	1.4	50.
6-3	366	Communications Equipment	3	4.8	74.
6-4	367	Electronics Components	2	8.2	64.
6-5	381	Engineering and Scientific Instr.	3	0.4	65.
	382	Measuring and Control Instr.		2.7	
Super Group 7 General Fabrication and Assembly (Total use 86.0 tBtu, 19% of this survey)					
7-1	372	Aircraft and Parts	2	9.2	47.
7-2	376	Guided Missiles, Space Vehicles	2	6.7	56.
7-3	352	Farm and Garden Machinery	1	0.5	42.
	353	Construction, Mining, Related		2.5	
	371	Motor Vehicles and Parts		8.9	
	375	Motorcycles, Bicycles, Parts		0.2	
	379	Misc. Transportation Equipment		0.7	
7-4	344	Fabrication of Structural Metal Prods	1	4.5	35.
	348	Ordnance and Accessories		1.4	
	351	Engines, Turbines		0.3	
	354	Metalworking, Machinery		1.1	
	355	Special Industry Machinery		1.3	
	356	General Industry Machinery		1.8	

*ERC coverage of 2 digit SIC is not complete for SICs 20,26,29, and 32.

Table A.7(cont.)
Annual Energy Use of California Industries.*

Most data are presented as 3 digit SIC with aggregation according to ERC. The class number shows the annual energy use of each SIC or ERC defined group; class 1 members use more than 10 tBtu/yr, class 2 between 5 and 10 tBtu/yr, and class 3 with less than 5 tBtu/yr.

Group	SIC	Description	Class	Energy Use [tBtu/yr]	% Bldg. Srv.
Super Group 7 General Fabrication and Assembly (Total use 86.0 tBtu, 19% of this survey) (cont.)					
	361	Electric Transp. and Distr. Equipment		0.5	
	362	Electric Industrial Apparatus		1.1	
	373	Ship and Boat building		1.5	
7-5	342	Cutlery, Hand Tools, Genr'l Hardware	1	1.8	51.
	343	Heating Equipment, Plumbing Fixtures		1.6	
	345	Screw Machine Products		1.2	
	349	Misc. Fabricated Metal Products		2.5	
	358	Refrig. and Service Ind. Mach'y		1.1	
	363	Household Appliances		0.8	
	364	Electric Lighting and Wiring Equipmt.		1.3	
	369	Miscellaneous Electric Machinery		1.4	
7-6	341	Metal Cans and Shipping Containers	2	6.3	26.
7-7	27	Printing and Publishing	2	7.5	43.
7-8	383	Optical Instruments and Lenses	3	0.6	61.
	384	Surgical, Medical, Dental Instr.		1.1	
	385	Opthalmic Products		0.2	
	386	Photographic Equipment, Supplies		0.5	
7-9	25	Furniture and Fixtures	3	3.6	57.
7-10	23	Apparel and Similar	3	3.1	64.
7-11	39	Misc. Manufacturing	3	3.1	53.
7-12	241	Logging Camps and Contracts	3	2.7	15.
7-13	244	Wood Containers	3	0.5	56.
	245	Wood Bldgs. and Mobile Homes		0.3	
Super Group 8 Food and Kindred Industries (Total use 44.4 tBtu, 10% of this survey)					
8-1	201	Meat Products	2	5.0	11.
8-2	202	Dairy Products	2	6.3	6.6
8-3	204	Grain Mill Products	2	4.9	8.7
8-4	205	Bakery Products	3	4.9	8.0
8-5	207	Fats and Oils	2	6.6	2.2
8-6	208	Alc. and Non-alc. Beverages	2	8.5	4.6
8-7	209	Misc. Food Preps. and Kindred Prods	2	8.2	9.0

*ERC coverage of 2 digit SIC is not complete for SICs 20,26,29, and 32.

Table A.8

Purchased Source Fuel for Non-Process Uses in Industries for which Estimates are not Available as reported by ERC-1983 (All energies are site energy)

Group	Description	Electricity				Space Heating									% Total Service Energy
		Lighting		A/C Vent		Natural Gas		Dist. Oil		Resid. Oil		Other		% Space Htg.	
		tBtu	% Total	tBtu	% Total	tBtu	% Total	tBtu	% Total	tBtu	% Total	tBtu	% Total		
1-4	Plastics, Syn. Fibers	.03	.5	.01	.2	--	--	--	--	--	--	--	--	0	0.7
1-5	Drugs	.05	2.4	.48	24.0	.20	10	.05	2.4	--	--	.12	6.0	18.4	44.8
1-6	Misc. Chem. Products	.26	2.0	.51	4.0	1.54	12.0	--	--	--	--	.64	5.0	17.0	23.0
3-1	Fired Clay Products	.02	.2	.04	.4	.02	.2	--	--	--	--	--	--	.2	.8
3-2	Concrete, Gyp., Plaster	.03	.2	.04	.3	.04	.3	--	--	--	--	--	--	.3	.8
3-3	Abrasives, Asbestos	.06	0.7	.16	2.0	.16	2.0	--	--	--	--	--	--	2.0	4.7
4-1	Steel Mills	.06	.2	.06	.02	--	--	--	--	--	--	--	--	0	.4
4-2	Non-Ferrous Metals	.0	.1	.01	0.3	.05	1.3	--	--	--	--	--	--	1.3	1.7
4-3	Foundries	.07	0.9	.15	2.0	.26	3.4	--	--	--	--	--	--	3.4	6.3
4-4	Metal Forming	.28	1.5	.37	2.0	.92	5.0	--	--	--	--	.10	.5	5.5	9.0
5-1	Textiles	.12	2.0	.45	7.5	.60	10.0	--	--	--	--	--	--	10.0	19.5
5-2	Paper Conversion	.19	2.5	.88	12.0	.96	13.0	--	--	--	--	.14	2.0	15.0	29.5
5-3	Asphalt, Misc. Petrol.	.08	.1	.08	.1	.08	.1	--	--	--	--	--	--	.1	.3
5-4	Rubber Products	.12	2.0	.25	4.0	.31	5.0	--	--	--	--	--	--	5.0	11.0
5-5	Plastics Products	.22	2.1	.43	4.2	.52	5.0	.05	.5	--	--	.15	1.5	7.0	13.3
5-6	Leather Products	.01	1.2	.04	4.5	.09	10.0	--	--	--	--	--	--	10.0	15.7
6-1	Comp. & Office Mach.	.60	17.0	1.19	34.0	.60	17.0	.07	2.0	--	--	.07	2.0	21.0	72.0
6-2	Home Electronics	.10	7.0	1.5	11.0	.22	16.0	.11	8.0	.03	2.0	.08	6.0	32.0	50.0
6-3	Communications Equip.	.76	15.5	1.47	30.0	.99	20.2	.25	5.0	.10	2.0	.07	1.5	28.7	74.2
6-4	Electronic Components	.57	7.0	2.46	30.0	1.04	12.7	.16	2.0	--	--	.98	12.0	26.7	63.7
6-5	Electronic Instruments	.28	9.0	.65	21.0	.40	13.0	.03	1.0	--	--	.65	21.0	35.0	65.0
7-1	Aircraft	1.29	14.0	1.20	13.0	1.38	15.0	.37	4.0	.06	.7	.05	.5	20.2	47.2
7-2	Spacecraft & Missiles	.96	14.4	1.37	20.5	1.07	16.0	.27	4.0	.11	1.6	--	--	21.6	56.5
7-3	Motor Vehicles	.90	7.0	.90	7.0	3.20	25.0	.04	.3	.08	.6	.26	2.0	27.9	41.9
7-4	Heavy Machinery	.82	6.0	1.08	8.0	1.36	10.0	.27	2.0	.14	1.0	1.09	8.0	21.0	35.0
7-5	Light Machinery	1.50	10.0	1.95	13.0	3.38	22.5	.15	1.0	.06	.4	.60	4.0	27.9	50.9
7-6	Metal Containers	.06	1.0	.25	4.0	1.35	21.4	--	--	--	--	--	--	21.4	26.4
7-7	Printing, Publishing	.40	5.3	1.43	19.0	.60	8.0	.15	2.0	.15	2.0	.53	7.0	19.0	43.3
7-8	Optical & Med. Instr.	.18	7.5	.58	24.0	.48	20.0	.03	1.3	--	--	.19	8.0	29.3	60.8
7-9	Furniture	.36	10.0	.61	17.0	.54	15.0	--	--	--	--	.54	15.0	30.0	57.0
7-10	Apparel	.37	12.0	0.62	20.0	.43	13.8	--	--	--	--	.56	18.1	31.9	63.9
7-11	Misc. Mfd. Products	.31	10.0	.43	14.0	.31	10.1	.09	3.0	--	--	.50	16.0	29.1	53.0
7-12	Logging	.04	1.3	--	--	--	--	.26	.6	.03	1.0	.09	3.4	14.0	15.3
7-13	Misc. Wood Products	.07	9.0	.11	14.0	.16	20.0	.07	9.0	--	--	.03	4.0	33.0	56.0
8-1	Meat Products	.21	4.2	.15	3.0	.15	3.0	.05	1.0	--	--	--	--	4.0	11.2
8-2	Dairy Products	.07	1.0	.10	1.5	.23	3.5	.01	0.1	--	--	.03	.5	4.1	6.6
8-3	Grains & Feeds	.10	2.0	.05	1.0	.20	4.0	.01	.2	.0	.1	.07	1.4	5.7	8.7
8-4	Bakery Products	.15	3.0	.05	1.0	.2	4.0	--	--	--	--	--	--	4.0	8.0
8-5	Fats & Oils	.04	.6	.03	.5	.07	1.0	--	--	--	--	.01	.1	1.1	2.2
8-6	Alc./Non-Alc. Bev.	.09	1.0	.05	.6	.17	2.0	--	--	--	--	.09	1.0	3.0	4.6
8-7	Misc. Food Products	.16	2.0	.12	1.5	.33	4.0	.04	.5	--	--	.08	1.0	5.5	9.0
	Totals	12.0	2.7	21.0	4.7	24.6	5.5	2.53	.5	.76	.2	7.8	1.7	7.9	15.3
	% of Non-Process Energy by Category		17.		31.									52.	

Appendix 5
Booz, Allen and Hamilton, Inc. (BAH)

We examined the fragmentary regional data available from in analysis of Pacific Gas and Electric's (PG&E) industrial audits by Booz, Allen and Hamilton, Inc. (BAH) This analysis is published in a report, [2], by BAH to PG&E, dated 2/26/86.

BAH addressed four tasks:

Task 1: Use the data base to identify energy use trends in several industry groupings.

Task 2: Use the above analyses performed in Task 1 as a guide to select more focused, issue-oriented analyses of business trends.

Task 3: Identify several ways in which the data base might be improved or expanded to accommodate the business issues analyzed above.

Task 4: Document findings and conclusions, and offer recommendations.

Electricity and Gas Sales Trends

This study covers sales from 1981 - 1984 indicating energy use trends during this period, and it shows ways in which this industrial data base can be used to identify overall industry trends. Industrial energy use is often analyzed at the four-digit SIC level because many two-digit SIC industries are too diverse to make up an adequate trend model.

In 1984, five industrial categories were responsible for 63% of total PG&E industrial electricity sales of 15.8 billion kWh. These were:

1. petroleum refining,
2. oil and gas extraction,
3. food and kindred products,
4. electronics and electronic equipment products, and
5. stone, clay, and glass products.

The five industrial categories that purchased 83% of total PG&E gas sales of 1,400 MMTherms or 140 TBtu, in 1984, were:

1. petroleum refining,
2. food and kindred products,
3. stone, clay and glass products,
4. chemicals and allied products, and
5. paper and allied products.

It is important to take into account the dynamic character of these important industrial sectors in planning future energy needs. During the four years of data studied, PG&E sales to the industries that purchased the greatest quantities of energy (petroleum refining, SIC 2911, and food and kindred, SIC 20) decreased. Energy purchases by oil refineries decreased at about 12% Compound Annual Growth Rate (CAGR), while purchases from the food industry decreased about 1.4% CAGR. Purchases by the stone, clay, and glass industries, SIC 32, decreased by approximately 9% CAGR; those by chemicals and allied products, SIC 28, by about 15%; and those by primary metals, SIC 33, by about 5% CAGR.

The major industries which demonstrated overall growth of energy purchases were oil extraction, SIC 13, increasing about 14% CAGR; electronics and electronic equipment, SIC 36, increasing about 9%; machinery except electrical, SIC 35, about 8%; fabricated metal products, SIC 34, about 4%; and paper and allied products, SIC 26, about 3% CAGR.

The purchase pattern for natural gas from 1981-1984 is similar to that observed during this time for overall energy purchases. Only three major industry groups expanded gas purchases. These increases ranged from approximately 14% CAGR for oil and gas extraction, SIC 13; approximately 5% for electronics and electronic equipment, SIC 36; to approximately 3% for paper and allied products, SIC 26.

Of the seven major industries showing decline in gas purchases, petroleum refining, SIC 2911, and chemicals and allied products, SIC 28 showed the largest decline of about 17% (when in expressed as compound annual (negative) growth rate). Primary metals, SIC 33, and stone, clay, and glass products, SIC 32, each showed about 10% negative CAGR. Fabricated metal products, SIC 34, and food and kindred products, SIC 20, showed similar negative CAGRs of approximately 3%, and machinery except electrical, SIC 35, showed approximately 1% negative CAGR.

Electricity sales during the same period to the same industries showed rapid growth rates except in chemicals and allied products, SIC 28, with CAGR of -2%; paper and allied products, SIC 26, with approximately -0.5%; and stone, clay, and glass products, SIC 32, with approximately +0.8% CAGR. Those showing strong growth rates were primary metals, SIC 33, with 6.5%; food and kindred, SIC 20, with 7%; electronics and electronic equipment, SIC 36, about 11%; petroleum refining, SIC 2911, about 13%; oil and gas extraction, SIC 13, about 14%; machinery except electrical, SIC 35, about 14.5%; and fabricated metal products, SIC 34, with the highest CAGR of about 22%.

The major reasons for the decrease in gas sales to oil refineries were a decrease in refining output and the phasing-out of electricity-for-fuel agreements between PG&E and three of its major refinery customers.

The changes in purchased energy by SIC 32, the stone, clay, and glass industry, reveal that electricity revenues increased by approximately $10 million while gas revenues decreased by approximately $17 million. The largest changes were the result of a conversion from natural gas to coal by the cement plants in California and the increased use of electricity for forehearths and lehrs in the glass container industry, in spite of the fact that the ratio of average electricity to gas prices in PG&E's glass industry increased 6% between 1981 and 1984.

PG&E's industrial sales are highly concentrated, with 100 of the largest industrial plants purchasing 45% of the total industrial sector sales in 1984. Concentration of gas sales shows that the 100 largest consuming plants purchased 76% of the total industrial gas sales in 1984. Electricity sales to the top 100 plants accounted for 52% of total industrial sector use.

Energy End Use of Selected Industries

Efforts to study the industries within PG&E's service territory for energy end-use efficiency include analysis of the company's industrial data base. As of 1984, 37% of SIC 2911 electricity purchases were included in PG&E's Energy Utilization Audits (EUA), 67% of SIC 1311, 33% of SIC 3573, 43% of SIC 3674, 70% of SIC 2421, 5% of SIC 2819, 98% of SIC 3312, 25% of SIC 3241, and 53% of SIC 3079.

Of the major gas-consuming industries, 9% of all facilities in SIC 2911 was included in PG&E's EUAs, 53% of SIC 2133, 48% of SIC 2819, 26% of SIC 3221, 3% of SIC 2621, 16% of SIC 2061, 29% of SIC 1311, 52% of SIC 2034, and 57% of SIC 3275.

The BHA report analysis states that the proportion of an industry's electricity (gas) purchases which have been included in EUAs exceeds half in only four (three) of the nine homogeneous industries, with the greatest electricity (gas) purchases from PG&E. As a result some industries are excluded from meaningful conservation and demand-side management analysis.

The availability of data on electricity and gas purchases by major end use is helpful in determining which industry or plants could benefit from new technologies such as cold storage or cogeneration.

As an example of the type of analysis that can be undertaken with the present data base, BAH examined air-conditioning loads of several industries which were expected to have significant electrical demand. EUA information on the percentages of total electricity consumption used for space cooling systems by four-digit SICs is shown on Table A.9.

Table A.9

Percentages of Total Electricity Consumption Used for Space Cooling Systems by 4-Digit SICS

Industry	SIC Code	%
Semiconductors	3674	39
Computers	3573	36
Guided Missiles and Space Vehicles	3761	23
Plastics	3079	10

Also note that of the 100 sites purchasing the greatest amounts of electricity in SIC 3573, 47 were audited, and, in SIC 3674, 41 were audited. BAH believes semiconductors and computers are the industries showing the greatest potential for cool storage technology (thermal energy storage, TES). According to PG&E EUA data, certain groups within the food industry, such as frozen fruits and vegetables, SIC 2037, and frozen specialties, SIC 2038, use more than 50% of the electricity in their plants for refrigeration. These industries may also be able to take advantage of TES; however, the technology of integrating cold storage units into refrigeration systems, though in principle understood, has not been developed to the extent that cold storage and space cooling systems technology has. The electricity use in these industries may be more akin to base load profiles, reducing somewhat the economic advantages of TES.

According to PG&E EUA data, space cooling is the largest energy end use for the semiconductor industry, SIC 3674, and the computer industry, SIC 3573. For the semiconductor industry, SIC 3674, energy uses by end use are: air conditioning 39.2%, lighting 12.4%, motors 13.0%, hot water 0.1%, miscellaneous (possibly computers or other office equipment) 9.1%, process heat 25.7%, and space heating 0.5% of the total energy purchased; and for the computer industry, SIC 3573: air conditioning 36.4%, lighting 26.7%, motors 16.4%, hot water 0.3%, miscellaneous 12.2%, process heat 7.3% space heat 0.3%, and refrigeration 0.4%.

The above figures are averages. But if a site-by-site analysis is undertaken, one finds a large variation in the fractions of the total electrical consumption that is used for air conditioning even within the same four-digit SIC code. The PG&E data base shows for example that, in the semiconductor industry, SIC 3674, use of electricity for air conditioning as a percentage of total kWhs purchased, varies from 5% to nearly 70%, and the like figures for the computer industry, SIC 3573, vary from negligible to more than 70%. Depending upon the reliability of the data base, other industries should be explored for energy conservation potentials. To establish the validity of the wide variations indicated above for air conditioning, climatic factors must be examined. In projecting energy use for future growth, more detailed information must be gathered to construct reliable demand forecasting models. Locating a plant of the same four-digit category a few miles closer to or farther from the coast may dramatically affect space conditioning requirements.

Recommendations of BAH

BAH has made suggestions to PG&E concerning their industrial data base; the relevant ones are mentioned below:

1. Cross-reference this data base with Dun & Bradstreet's Major Industrial Plant Data Base (MIPD), and include in PG&E's data base, as MIPD does, such characteristics as capacity utilization rates (by plant and major boilers). Capacity utilization could be used as an indicator for output trends, making it possible for PG&E to analyze industry and firm specific trends.
2. Include fuel and electricity usage by major process step, which could be used in targeting marketing programs, such as those that might benefit from Thermal Energy Storage (TES).
3. Include capacity of boilers with fuel switching capability and their primary and secondary fuels, which would provide data for analysis of fuel switching potential.
4. Include information on current and planned cogeneration systems in the industrial data base, which would make impacts of cogeneration investments on electricity and gas purchases amenable to analysis; include cogeneration capacity, fuels used, completion date, and present status.
5. Include load shape data in the data base, showing monthly values for on-peak, off-peak, and shoulder electricity demand. Such information would facilitate identification of industries and plants where load shape management programs should be adopted.
6. Frequently update EUA's and extend coverage to more of the largest users.

Appendix 6
ASHRAE Industrial Energy Conservation Awards

Example 1

Author: Staff writer
Title: "Taking on a Heavyweight (An energy efficient industrial plant)"
Date: March 1985
Publication: ASHRAE Journal vol. 27:3 p.59-61

Summary:

This article describes the ASHRAE award recipient in the new industrial classification for Northern Alberta (Canada). In 1981, Bennett & Emmott Limited constructed a new facility in Edmonton, Alberta, Canada. The purpose of the new facility was to extend and improve plant operations while increasing energy efficiency. The floor area and volume are doubled in the new $2,278,728 facility.

The company is involved with the design, manufacturing, sales, and service repair of heavy industrial electrical machinery. Plant operations include welding and machining of large industrial equipment. The new facility also houses three office areas: east, west, and north. (The number of total employees not was cited.)

The building's gas-fired radiant heating is both more comfortable for the employees and more energy efficient than the previous heating system. Normal plant operations require that heavy equipment is moved from the outdoors. Radiant heating of the concrete floors eliminates the need for moving heated air around the plant. Less energy is lost in the high bay work area and to the outdoors.

The office area is both ventilated and cooled by three roof-top constant volume units. They are time controlled to operate during working hours only. Hot water radiation is used for winter heating.

Other conservation measures include wall and roof installation (values of RSI 3.7), stratified waste heat storage, changes to the building's electrical system, and high-pressure sodium vapor lighting in high bay areas.

When comparing the old facility with the new, we find a 55% reduction in the total energy consumption/unit floor area. In spite of increased plant production levels and increased floor area and volume, the new facility consumes 33% less natural gas.

No energy end-use values were published.

Example 2

Author: Staff writer
Title: Florida Steel Corporation Charlotte Plant, North Carolina
Date: June 1984
Publication: ASHRAE Entry form **4F**

Summary:

The Florida Steel Corporation entered its Charlotte, North Carolina plant in the ASHRAE Awards Program--Existing Industrial Facility or Process. The steel mill primarily produces steel bars that are used to reinforce concrete in the construction industry.

The one-story plant covers 202,805 ft^2. Of the several adjustments made to the plant, the lighting conversion is of particular interest. The electrical lighting system was converted from mercury to high pressure sodium. They note that this conversion is applicable to any high bay applications. By using the energy efficient HPS system, they were able to save approximately half of the cost of expanding the mercury electrical system.

Table A.10 characterizes the functional uses of its major areas:

Table A.10

Percentage Floorspace by Activity and Hours in Example 2

Percentage floorspace by activity and hours worked		
Functional Use of Major Areas	*% of Area Used For That Function*	*Hours Used Per Week*
Melt Shop	25.5	120
Mill Shop	34	120
Fab Shop & Rod Storage	20.5	120
Maintenance Shop & Offices	2	120
Billet Storage	18	120

Table A.11 describes energy uses and costs before and after system retrofitting was finished.

Table A.11

Energy Uses and Costs: Before and After System Retrofitting was Finished in Example 2

Energy Cost and Use Prior to Retrofit		
Energy Type	*Total Units*	*Cost*
Electric [kWh]	129,421,200	$5,276,500
Natural Gas [cu ft.]	308,688,000	$1,512,600

Energy Cost and Use After Retrofit		
Energy Type	*Total Units*	*Cost*
Electric [kWh]	126,559,400	$5,160,100
Natural Gas [cu ft.]	304,148,800	$1,490,300

Example 3

Author:
Title: Hazleton Laboratories America, Vienna, Virginia
Date: October 1985
Publication: ASHRAE Entry form **4G**

Summary:

Hazleton Laboratories America is a biological research laboratory located in Northern Virginia. The 42-acre site has several buildings that range from 19 to 37 years old.

The largest laboratory is a three-story, 71,237-square-foot building. In 1967, when the building was constructed, the absorption chiller was relatively inexpensive to operate and maintain. However, when gas prices began increasing in the late 1970's and continued to do so through the early 1980's, Hazleton Laboratories considered replacing the absorption chiller with a centrifugal chiller. By 1982, the absorption chiller was functioning solely as a backup to the centrifugal chiller, which supplied chilled water for the building cooling systems.

Table A.12 characterizes the functional uses of its major areas:

Table A.12

Functional Use of Major Areas in Example 3

Percentage Floor Space by Activity and Hours Worked		
Functional Use of Major Areas	*% of Area Used For That Function*	*Hours Used Per Week*
Laboratory	65	168
Office	34	55
Maintenance	12	168
Common Use	20	168

Table A.13 characterizes the energy consumption before and after the absorption chiller was replaced. (These data were calculated from Washington Gas Light Company & Vepco utility bills.) Note the change in the ratio of energy per square foot and in the cost per square foot.

Table A.13

Energy Consumption Before and After the Absorption Chiller was Replaced in Example 3

Energy Cost and Use Prior to Retrofit			
Energy Type	*Total Units*	*Btu/unit (On-site energy use)*	*Cost*
Electric	4,334,592	3,413	$275,600
Natural Gas	436,110	100,000	$279,100
Btu per year-square foot		819,999	
Cost per year-square foot			$7.22
Energy Cost and Use After Retrofit			
Energy Type	*Total Units*	*Btu/unit (On-site energy use)*	*Cost*
Electric	4,336,832	3,413	$297,000
Natural Gas	216,591	100,000	$138,600
Btu per year-square foot		511,939	
Cost per year-square foot			$6.11

When comparing the energy use profile of this building with the profile presented by NBECS, we note that Hazleton Laboratories are located in the least densely populated industrial sector in the country and are seven times larger than the average industrial building (1,000 to 10,000 square feet is the most common gross floor area.) Also, most industrial buildings have only one floor, while this building had three floors. The laboratory operated on the average of three times more frequently during the week than its counterparts.

Neither monthly utility bills or energy end-use data were published.

Example 4

Author: Staff writer
Title: Graham-White Manufacturing Company
Alternative or Renewable Energy Utilization: FIRST PLACE
Date: March 1983
Publication: ASHRAE Journal vol. 25:3 p.52-53

Summary:

The Graham-White Manufacturing Company located in Salem, Virginia manufactures machine parts and components for various industries. It won an ASHRAE award in the Alternative and/or Renewable Energy Use category for its enlarged plant.

Once the company decided to expand its operation, several changes had to be made to the original plant. The one-story existing 18,000 square foot plant was renovated and 2,000 square feet were added. Then, a 20,000-square-foot second floor was built. The 40,000-square-foot plant contains: offices, test lab, drafting room, coil molding room, break room, and a parts storage area. According to the NBECS, only 12% of all industrial buildings are this size: from 25,001 to 50,000 square feet. Table A.14 characterizes the functional uses of its major areas:

Table A.14

Functional Uses of Major Areas in Example 4

Percentage Floor Space by Activity and Hours Worked		
Functional Use of Major Areas	*% of Area Used For That Function*	*Hours Used Per Week*
Office/administrative	9	40
Manufacturing	17	80
Warehouse/Storage	33	80
Cafeteria/Break Room	12	80
Cleaning & Degreasing	14	80
Coil Molding	15	80

The occupied building temperature is maintained 24 hours a day. All 40,000 square feet are heated with the heat rejected by an industrial air compressor and cooled with well-water. (The space conditions satisfy ASHRAE recommendations.) The multizone air handling unit containing a water type heating and a water type cooling coil provide heat and cooling for the entire area.

Because the total (building) heating load is less than the total amount of heat rejected from the air compressor, the excess was used to maintain building space temperature during the heating season. With this arrangement, there is basically no charge for heat. The only energy needed is that that is required to move the heat from the compressor to the air handling unit through the heating coil.

Well-water is received for the cooling water circuit. If none of the seven control zones have water collected, the valve is closed. The system provides up to 201 gpm (maximum cooling flow rate) of 56°F well-water cooling coil: The well-water pump consumes 7 kWh and 70 kWh for cooling in the condenser.

The cost of the system was $82,550, which is less than 10% of energy costs of conventional systems ($12,304). Table A.15 characterizes the energy cost and consumption of the new plant:

Table A.15

Energy Cost and Consumption of the New Plant in Example 4

Energy Cost and Consumption			
Energy Type	*Total Units*	*Btu/unit (On-site energy use)*	*Cost*
Electric	307,616	3413	$12,304
Btu per year-square foot		26,248	
Cost per year-square foot			$0.308

In comparison with the profile of industrial buildings presented in the NBECS, this building is somewhat typical. Electricity use is very common: 99.6% of industrial buildings use electricity. However, the use of a two-fuel combination is more common than one-fuel combinations: 67.1% of industrial buildings use a combination of two different fuels. Also, most industrial buildings are one-story and not two. The operation hours for this plant are approximately twice as long as for any other industrial plant.

No energy end-use data provided.

Example 5

Author: Staff writer
Title: Getting the Right Chemistry (New Industrial Facility)
Date: March 1985
Publication: ASHRAE Journal vol. 28:3

Summary:

The H. B. Fuller company's **Willow Lake Laboratory**, built in Vadnais Heights, Minnesota, is used for chemical product research and development. When the building was designed, conserving energy was one of the primary focuses. A unique constraint affecting this project was the adjacent wildlife preserve. Accordingly, the heating/cooling plant is designed not to harm the Protected Wildlife Preserve.

This three-story laboratory occupies 101,000 square feet. The size is abnormally large for an industrial building. The usual range is from 1,000 to 10,000 square feet. The spatial distribution and hours of operation are described in Table A.16.

Table A.16

Spatial Distribution and Hours of Operation in Example 5

Percentage Floor Space by Activity and Hours Worked		
Functional Use of Major	*% of Area Used for that Function*	*Hours Used per Week*
Laboratories	70	56
Offices	30	56

Well water is the source for the heat pumps that provide variable hot water supply temperatures. When the building requires less heat due to occupancy shifts or outside weather conditions, the pumps supply cooler water. Similarly, the need for cooling is monitored, and the speed of the well pump controlled. The laboratory is completely cooled by the use of well water in the fan cooling coils.

The heat pump service costs approximately $12,000 per year. If a conventional boiler service, condensate, and feed-water treatments were used, the cost would be roughly $4,000. The net cost for heating is $8,000 higher than the cost of conventional heating methods. This system requires $10,000 per year for chemical treatment and $3,000 per per year for annual cooling-coil cleaning. However, this is $10,000 less than the cost of a conventional cooling system: cooling tower chemical treatment, $6,000; chiller service, $5,000; cooling tower service, $5,000. Hence, the total benefit of the well-water system, including the cooling system costs, is $2,000 per year. Table A.17 characterizes the energy consumption and costs.

Table A.17

The Energy Costs and Consumption in Example 5

Energy Costs and Consumption			
Energy Type	*Total Units*	*Btu/unit (On-site energy use)*	*Cost*
Electric (well water system only)	1,561,923	3413	$68,725
Electric (total facility)	*4,433,200*	*3413*	*$196,386*
Btu per year-square foot (well water system only)		52,811	
Cost per year-square foot (well water system only)			$0.68

In comparison with the profile of industrial buildings presented in the NBECS, this building is somewhat typical. The use of electricity is very common: 99.6% of industrial buildings use electricity. However, the use of a two-fuel combination is more common than a one-fuel: 67.1% of industrial buildings use a combination of two different fuels. Also, most industrial buildings are one-story and not three. The operation hours for this plant are approximately the same as for most of the other industrial plants.

Monthly utility data are available.

Example 6

Author: Staff writer
Title: Vacuum System Energy and Utility Recovery by Eli Lilly & Company
Date: June 1984
Publication: ASHRAE Entry form **4D**

Summary:

This pharmaceutical and cosmetic facility, located in Indianapolis, Indiana, won an ASHRAE award for its modified vacuum system and water recirculation system. The four-story building occupies 240,181 square feet. This includes the basement, first through fourth floors, and the penthouse.

In this project, the recently modified vacuum steam ejectors barometric condenser cooling system was modified from a once-through (city water to sewer) to a 90% recirculation system. Hence, both water and costs are conserved. Heat was removed from the recirculated water and used for heat in the building's main fan system. Prior to this project, the heat had been supplied by the purchased steam for space heating (where it was economically possible).

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720