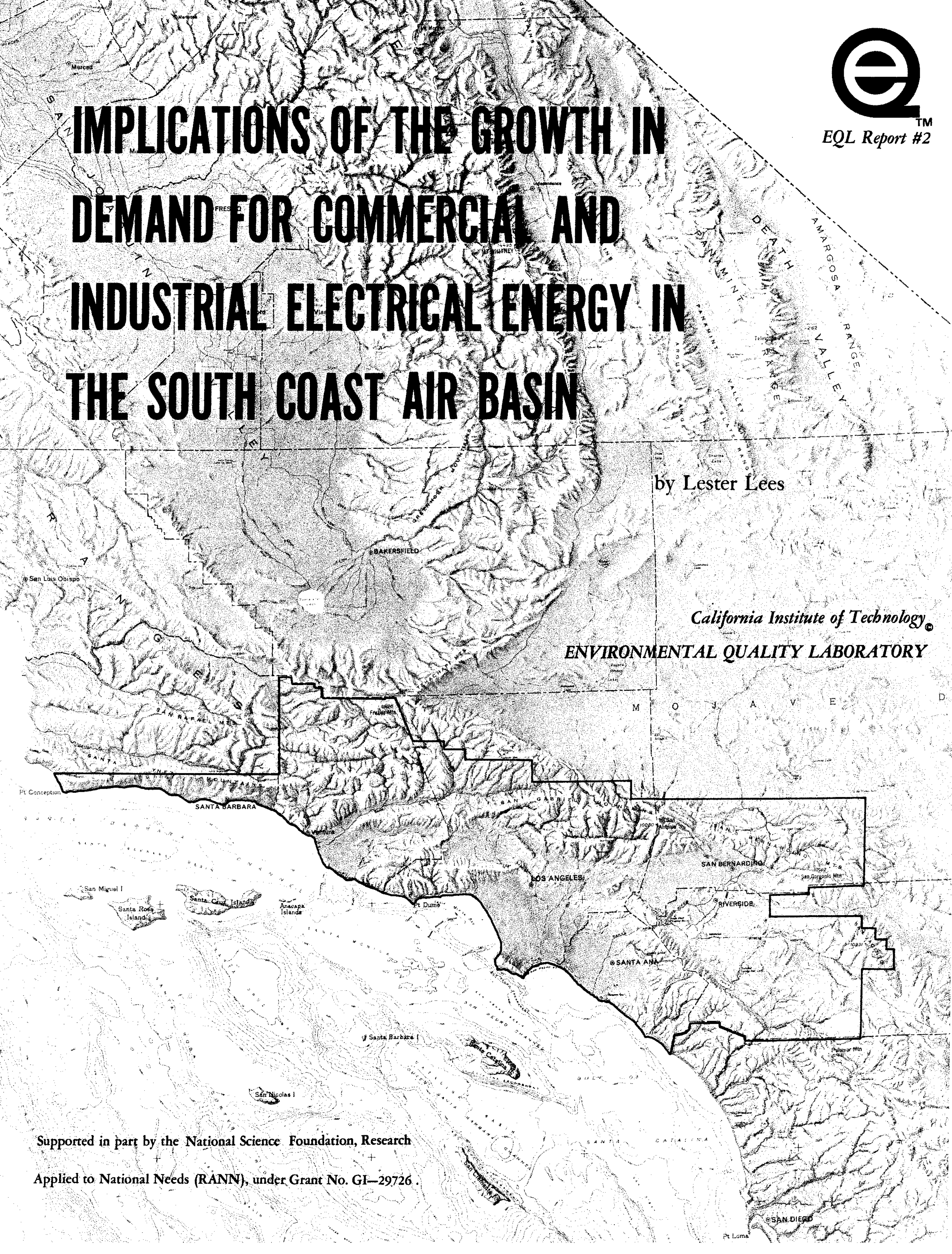
EQL Report #2

# IMPLICATIONS OF THE GROWTH IN DEMAND FOR COMMERCIAL AND INDUSTRIAL ELECTRICAL ENERGY IN THE SOUTH COAST AIR BASIN


by Lester Lees

*California Institute of Technology*

*ENVIRONMENTAL QUALITY LABORATORY*



Supported in part by the National Science Foundation, Research Applied to National Needs (RANN), under Grant No. GI—29726.

Report #2

# *IMPLICATIONS OF THE GROWTH IN DEMAND FOR COMMERCIAL AND INDUSTRIAL ELECTRICAL ENERGY IN THE SOUTH COAST AIR BASIN*

*by*

*Lester Lees*

*November, 1971*

*Supported in part by the National Science Foundation, Research Applied to National Needs (RANN), under Grant No. GI-29726.*

*California Institute of Technology*©
*ENVIRONMENTAL QUALITY LABORATORY*

*Table of Contents*

*Acknowledgements*

*The author would like to express his appreciation to Miss Patti Horne, research aide at the Environmental Quality Laboratory, for her assistance in collecting most of the statistical data utilized in this report, and to Mr. Paul Myers, Supervising Environmental Planning Engineer, Southern California Edison Company, for his kind cooperation in supplying unpublished data on various aspects of electrical energy demand.*

*Summary*

An examination of statistical data for the period 1960-1970 shows a simple correlation between the growth in demand for commercial electrical energy in the South Coast Air Basin and the growth in commercial floor area and in electrical loading per square foot. Demand for industrial electrical energy correlates strongly with value added by manufacture and with kilowatt-hours per dollar of value added; growth in manufacturing floor area is a secondary factor. These simple correlations are utilized to forecast future demand for electrical energy in the Basin in terms of plausible "minimum" and "maximum" rates of economic growth. Comparisons between these demand projections and conservative estimates of available electrical generating capacity bring out the "tightness" of the short-run demand-supply situation. A "management standard" for growth in demand for electrical energy of 5% per year is suggested as a goal for the mid-1970's. Long-range implications of environmental, land use and technological constraints on electrical energy supply are examined and related to possible limitations on the rate of economic expansion in the South Coast Air Basin. Conversely, one can utilize the results of this study to estimate the relationship between a desired rate of economic growth and the demand for electrical energy.

*List of Symbols and Abbreviations*

| | |
|---|---|
| B | one billion |
| $ft^2$ | square feet |
| KWH | kilowatt-hours |
| $(KWH)_c$ | commercial electrical energy demand |
| $(KWH)_I$ | industrial electrical energy demand |
| LADWP | Los Angeles Department of Water and Power |
| M | one million |
| MW(e) | megawatts (electrical) |
| $S_c$ | commercial floor area, $ft^2$ |
| $S_M$ | manufacturing floor area, $ft^2$ |
| $\Delta S_c$, $\Delta S_M$ | yearly increments in $S_c$ and $S_M$, respectively, $ft^2$ |
| SCE | Southern California Edison Company |
| V | value added by manufacture, $ |
| $\Delta$ V | yearly increment in V, $ |
| Y | year A.D. |

# 1 INTRODUCTION

Because of the complexity of environmental problems on the global or national level it seems worthwhile to tackle these problems first on a smaller scale in order to build up an understanding of the major competing forces involved. Thus, Dr. John List of Caltech's Environmental Quality Laboratory has just completed a study of the supply, utilization and relative pollution production of all forms of energy in all of the air basins of the State of California.* One of these regions, the South Coast Air Basin in Southern California, has been selected by the EQL for more intensive investigation of environmental problems. This basin is a "sub-empire" in itself, containing more than 11 million people, or about 55% of the population of California, and including all of Ventura and Orange Counties, most of Los Angeles County, and parts of Santa Barbara, Riverside and San Bernardino Counties. The people of this region share much more than a common air pollution problem. They are dealing with similar questions of water resources management, energy supply and use, transportation, urban sprawl, land planning and land use. They are also faced with the difficult task of reenergizing or restructuring existing institutions, or even creating new ones, to help them cope with these questions.

As Dr. List's study shows, the ways in which a region supplies and uses its energy resources have a strong impact on the environment of the region. This observation is especially true of electrical energy. In the South Coast Air Basin (as in the rest of California) the demand for electrical energy has been growing at a phenomenal equivalent exponential growth rate of 8.5%/year during the period 1960-1969, corresponding to a doubling time of about 8 years. Some studies of the major factors stimulating residential electrical energy demand have been made (See, for example, Reference 1), but not much is known about the commercial and industrial sectors. These two sectors together account for more than half the total demand.

The purpose of this report is to relate the growth in demand for commercial and industrial electrical energy to the main driving economic forces in these sectors. As a first attempt the period 1960-1970 is selected for study, partly because good statistical data on the major economic indicators in the South Coast Air Basin are available for this period. However, the purpose of this investigation is not simply historical curiosity. If approximate but relatively simple correlations can be established these correlations will be helpful in tying projections of future electrical energy demand to various predictions of the possible rates of economic expansion in this Basin. This link is an important one in the complex "feedback loop" illustrated schematically in Figure 1.

---

* E. John List, "Energy Use in California – 1969", to be published shortly as an EQL report.

In Section 2 the major factors influencing the demand for commercial electrical energy in the South Coast Air Basin are examined, and a simple correlation is sought in terms of the growth in commercial floor area and the increase in electrical loading per square foot of floor area. Section 3 deals with the major economic and technical factors influencing the growth in the demand for industrial electrical energy. The correlations established in Sections 2 and 3 are utilized in Section 4 to forecast future demand for electrical energy in the Basin. Plausible "maximum" and "minimum" growth rates are compared with projections of available electrical generating capacity. Finally, in Section 5 the long range implications of environmental, land use and technological constraints on electrical energy supply are examined and related to possible limitations on the rate of economic expansion in the South Coast Air Basin.

# 2 GROWTH IN DEMAND FOR ELECTRICAL ENERGY IN THE COMMERCIAL SECTOR

## 2.1 Factors Influencing Demand for Commercial Electrical Energy

Even a casual observer living in the South Coast Air Basin is aware of the enormous expansion in the number of large retail shopping centers, banks and high-rise office buildings in this region over the last 10-15 years. These new commercial structures have better interior lighting than older buildings, and in many of the new high-rise structures the lights are never turned off.* An increasing percentage of these new buildings are "all-electric". In fact, 22.4% of the number of new industrial and commercial meters connected by SCE in 1970 were all-electric installations;** the percentage of new floor space in this category is almost twice as large (Section 2.3).

These observations suggest that the strongest factors driving up the demand for commercial electrical energy are the growth in commercial floor area and the increase in electrical "loading" per square foot of floor area. As a first approximation suppose we postulate a simple functional relationship of the form

$$(KWH)_c = S_c \left(\frac{KWH/\ year}{ft^2}\right) \qquad (1)$$

where $(KWH)_c$ is the yearly commercial use of electrical energy in kilowatt-hours, $S_c$ is the commercial floor area in square feet, and $\left(\frac{KWH/year}{ft^2}\right)$ is the electrical loading in kilowatt-hours per year per square foot. Once the growth in $S_c$ over time is obtained from construction statistics, and the electrical loading is calculated or estimated, $(KWH)_c$ can be calculated and compared with data on the actual use of commercial electrical energy given in the annual financial and statistical reports of the Los Angeles Department of Water and Power and the Southern California Edison Company. ***

---

* The explanation usually given for this practice is that the small transformers in fluorescent lighting fixtures wear out sooner if the lights are switched on and off, and that the savings in labor costs achieved by reduced replacement rates outweight the increased costs of electrical energy incurred when the lights are never turned off. Also, leaving the lights on all night has no effect on peak demand.

** Private communication, Southern California Edison Company, Marketing Research and Analysis. (For 1970 the data includes only installations with a minimum floor area of 1500 square feet.)

*** These two utilities supply about 93% of the electric power requirements in the South Coast Air Basin.

Of course, the criticism can always be made that statistical time-series data on two different economic variables often show an arithmetic correlation even if the causal connection between these two variables is weak. A better check on the relation given by Equation (1) is provided by comparing the first differences $[\Delta (KWH)_c]_{CALCULATED}$ and $[\Delta (KWH)_c]_{ACTUAL}$ for each year.

*2.2 Growth in Commercial Floor Area*

Monthly and annual statistical data on construction contracts for new, addition and major alteration projects in non-residential buildings in the eleven Western States (Region VIII) are provided by the F.W. Dodge Division, McGraw-Hill Information Systems Company, 330 West 42nd Street, New York, New York, 10036.* This data is broken down into the following major categories: commercial buildings, manufacturing buildings, educational and science, hospital and health treatment, public, religious, amusement, social, and recreational buildings, and miscellaneous. Commercial structures are defined as stores and other mercantile buildings, warehouses (except those owned by manufacturers), office and bank buildings, and commercial garages and service stations.

For the seven major marketing areas in the South Coast Air Basin of California data is readily available only on total non-residential buildings.** Therefore, in order to obtain estimates of the yearly expansion in commercial floor area in the South Coast Air Basin the following procedure was used: The percentage of construction activity in non-residential buildings accounted for by commercial buildings in all of Region VIII was computed from the data for each year from 1960-1970, and these same percentages were applied to the data for total non-residential buildings for the seven major marketing areas in the South Coast Air Basin. Rough estimates for the current year 1971 were obtained by scaling up the data available for the first five months of the year by the factor 12/5.

In Table 1 we show the total yearly non-residential building in the South Coast Air Basin in millions of square feet ($Mft^2$), the percentage of commercial building in Region VIII, and the estimated yearly increase in commercial floor area, $\Delta S_c$, in $Mft^2$. (Total non-residential construction in each of the seven major marketing areas is tabulated in Appendix A). An estimate of total commercial floor area in the South Coast Air Basin at

---

* Region VIII consists of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

** The seven major marketing areas in the South Coast Air Basin are as follows: Anaheim-Santa Ana-Garden Grove (Orange County); Bakersfield; Los Angeles-Long Beach; Oxnard-Ventura; Riverside; San Bernardino; Santa Barbara.

the end of 1969 yields $S_c$= 640 million square feet (Section 2.3). By utilizing the tabulated values of $\Delta S_c$ for each year we obtain the time history of $S_c$ listed in Table 1.

One word of caution is necessary here: the F.W. Dodge construction statistics include major alteration projects as well as new or addition projects. Also, demolition statistics are not easy to obtain and are not available to the author at the present time. Thus, the values of $\Delta S_c$ given in Table 1 are probably somewhat too high.

### 2.3 *Electrical Loading of Commercial Structures*

Direct information on average electrical loading of all commercial structures in terms of KWH/year/ft$^2$ is not readily available. However, the marketing research section of SCE kindly provided the following information on average watts/ft$^2$:

*Commercial (office)*
*(watts/ft$^2$)*

| | 1960 | 1970 |
|---|---|---|
| Lighting | 2.5 - 3.0 | 3.5 - 4.0 |
| Convenience outlets | 1 | 1 |
| Heating | 7 | 6 |
| Air Conditioning | 5 | 5 |
| Water Heating | 0.1 - 0.5 | 0.1 - 0.5 |

By utilizing this information and by making reasonable estimates of the average number of hours/year in each category one arrives at estimates of average KWH/year/ft$^2$ for "light" and "heavy" commercial users.

Electrical loading for heavy "all-electric" commercial users in 1970 is estimated to consist of the following components:

Lighting: 8000 hours/year x 3.7 watts/ft$^2$ = 29.6 KWH/year/ft$^2$

Convenience outlets, Heating, Air Conditioning, and Water Heating:

2000 hours/year x 7.3 watts/ft$^2$ = 14.6 KWH/year/ft$^2$

TOTAL = 44.2 KWH/year/ft$^2$

For "light" users electrical loading in 1970 is estimated as:

$$\left.\begin{array}{l}\text{Lighting, Convenience}\\ \text{outlets, Water Heating}\end{array}\right\} \text{3000 hours/year x 5 watts/ft}^2 = \text{15 KWH/year/ft}^2$$

According to the data provided by SCE on resource class distribution approximately 63.4% of the commercial electrical energy used in Los Angeles County in 1969 was purchased by "heavy" users, and 36.6% by "light" users.* The actual data is as follows:

| Class | No. of Customers | KWH (1969) |
|---|---|---|
| "Light" | 89,242 | 1,882,634,243 |
| "Heavy" | 21,511 | 3,262,029,260 |
| TOTAL | 110,753 | 5,144,663,503 |

By utilizing the data on resource class distribution and electrical loading in each class the average KWH/year/ft$^2$ for all commercial electrical energy use is given by the following relation:

$$\text{Average KWH/year/ft}^2 = \frac{1}{\left(\frac{0.634}{44.2}\right) + \left(\frac{0.366}{15}\right)} = 25.7$$

By utilizing the data on revenue class distribution for commercial customers we can also obtain an estimate of the commercial floor area in each category, and the total commercial floor area in 1969.

For the "light" users,

$$\text{total floor space} = \frac{1.883 \times 10^9 \text{ KWH}}{15 \text{ KWH/ ft}^2} = 125.5 \text{ Mft}^2$$

For the "heavy" users,

$$\text{total floor space} = \frac{3.262 \times 10^9 \text{ KWH}}{44.2 \text{ KWH/ft}^2} = 74.2 \text{ Mft}^2$$

$$\text{Total, L.A. County, 1969} = 200 \text{ Mft}^2$$

---

* Private communication. The percentages for the entire SCE service area were 68.8% and 31.2%, respectively.

Total commercial electrical energy used in the South Coast Air Basin in 1969 according to the L.A. DWP and SCE reports was 16.413 billion KWH (References 2 and 3). By scaling up the figures for L.A. County we arrive at the following estimate of $S_c$ for the South Coast Air Basin in 1969:

$$S_c = \frac{16.413}{5.145} \times 200 \text{ Mft}^2 = 640 \text{ Mft}^2$$

The values of $S_c$ for other years are computed from this figure and the tabulated values of $\Delta S_c$. This procedure amounts to "matching" the total commercial $(KWH)_c$ and $\left(\frac{KWH/year}{ft^2}\right)$ for the year 1969 as a base data point.

In 1960 the percentage of commercial electrical energy utilized by "heavy" customers is estimated at 50%.* By utilizing the tabulated watts/ft$^2$ on page 5 the values of KWH/year/ft$^2$ for "heavy" and "light" users are estimated at 36.2 and 12.0 respectively. Thus, the average KWH/year/ft$^2$ for all commercial customers in 1960 is given by

$$\text{Average KWH/year/ft}^2 = \frac{1}{\left(\frac{0.50}{36.2}\right) + \left(\frac{0.50}{12}\right)} = 18$$

The increase in average electrical loading over the period 1960-1969 amounts to an equivalent exponential growth rate of about 4%/year. For calculation purposes we take

$$\left(\frac{KWH/year}{ft^2}\right) = 25.7 \exp \left[ 0.04 \; (Y - 1969) \right] \qquad (2)$$

where Y is the year A.D.

### *2.4 Comparison Between Estimated and Actual Commercial Electrical Energy Demand*

In Table 2 we list the values of $S_c$ from Table 1, the values of $\left(\frac{KWH/year}{ft^2}\right)$ calculated from Equation (2), and the values of the estimated yearly $(KWH)_c$ computed from Equation (1). Data on the actual values of commercial electrical energy use in the South Coast Air Basin listed in Table 2 were obtained from References 2 and 3. Also

---

* The exact figure is not available to the author at the present time.

tabulated in Table 2 are the first differences [ $(KWH)_c$ ] $_{ACTUAL}$ and [ $(KWH)_c$ ] CALCULATED.

Figure 2 shows the growth in commercial floor area and commercial electrical energy use in the South Coast Air Basin during the period 1960-1970. The agreement between the calculated and actual yearly $(KWH)_c$ is surprisingly close in the period 1960-1968.* Over this time period the equivalent exponential growth rate is about 10%/year, consisting of about 6%/year in the rate of expansion in commercial floor area and 4%/year in the average electrical loading. In the last three years it appears that the rate of increase in $(\frac{KWH/year}{ft^2})$ has slowed down to a value of about 1%/year, as compared with a rate of growth of 4%/year over the preceeding eight years. In other words, the watts/ft$^2$ and the percentage of commercial electrical energy utilized by the "large" customers are remaining nearly constant. This trend will be taken into account in making forecasts of future demand (Section 4).

A closer check on the simple correlation represented by Equation (1) could be made by obtaining data on the percentage of electrical energy used by "light" and "heavy" customers over the entire decade 1960-1970, by comparing the tabulated values of $(\frac{KWH/year}{ft2})$ in Table 2 with actual values for representative commercial structures, by tracking down the data on commercial construction, alterations and demolition in the seven major marketing areas of the South Coast Air Basin in order to improve on our estimates of $S_c$, etc. It would also be interesting to examine this correlation over the rest of the post-WWII period 1945-1960.

---

* In 1963 SCE completed its merger with California Electric, a privately-owned utility in the eastern part of the present SCE operating area. The SCE Annual Report for 1963 and all subsequent statistical reports list the combined KWH of both companies for all years prior to 1963 as if these sales had been made by SCE alone. The portion of the solid curve prior to 1963 in Figure 2 represents the data for SCE alone and the dotted curve represents the combined data.

# 3 GROWTH IN DEMAND FOR ELECTRICAL ENERGY IN THE INDUSTRIAL SECTOR

Demand for industrial electrical energy is driven up mainly by the growth in industrial output, by the increase in KWH per unit of output, and by the growth in floor area for manufacturing. A simple two-parameter description of the growth in industrial energy use is given by the following relation:

$$(KWH)_I = V \left(\frac{KWH/year}{\$}\right) + S_M \left(\frac{KWH/year}{ft^2}\right)_M \qquad (3)$$

Here V is the value added by manufacture ($), a quantity that is derived by subtracting the cost of materials, supplies, containers, fuel, purchased electricity and contract work from the value of shipments of products manufactured plus receipts for services rendered;* $\left(\frac{KWH/year}{\$}\right)$ is the average number of KWH per year per dollar of value added by manufacture; $S_M$ is the manufacturing floor area; $\left(\frac{KWH/year}{ft^2}\right)_M$ is the average KWH per year utilized for lighting and convenience outlets per square foot of manufacturing floor area (excluding electrical energy used in production).

Statistical data on the value added by manufacture in California for the years 1958-1967 are given in Reference 4. Data for the years 1965-1969, an estimate for 1970, and a forecast for 1971 are given on page 16 of Reference 5. Statistics on value added by manufacture for the seven major marketing areas in the South Coast Air Basin in 1963 and 1967 are also given in Reference 4. According to this data, the total value added for the Basin amounts to 64.5% of the figure for the entire state in 1967, and to 63.5% of the state figure for 1963. Since data for the Basin was not readily available for other years, a fixed percentage of 64.5% of the known California totals was applied to obtain estimates of value added by manufacture in the Basin in the period 1960-1970. These values (V) and the yearly increments $\Delta V$ are listed in Table 3.

Data on the growth of manufacturing floor area ($S_M$) in the South Coast Air Basin was obtained by means of a procedure similar to that used to estimate the growth in commercial floor area. The percentage of total non-residential building in Region VIII devoted to manufacturing was applied to the statistics on total non-residential building for the seven major marketing areas in the Basin (Appendix A). Values of yearly increments ($\Delta S_M$) are tabulated in Table 3. The total $S_M$ in 1969 is estimated at 600 $Mft^2$; from this

---

* For a more detailed discussion of value added by manufacture see Reference 4, page A-2.

figure and the values of $\Delta S_M$ one obtains the time history of $S_M$ (Table 3).

The electrical "loading" for manufacturing floor area in 1969 for lighting and convenience outlets (not production) is estimated at 5 watts/ft$^2$ x 2000 hours/year = 10 $(\frac{KWH/year}{ft^2})$. Its time history is approximated by the simple exponential growth function $(\frac{KWH/year}{ft^2})_M$ = 10 exp 0.02 (Y - 1969), where Y is the year A.D. For 1970 and 1971 this value is held fixed at 10 (Table 3).

The remaining important quantity is the KWH/year per dollar of value added by manufacture. Suppose we match the value of $(KWH)_I$ given by Equation (3) with the actual value of 18.17 billion KWH of industrial energy for 1970 (References 2 and 3 and Table 3). Since the values of V, $S_M$, and $(\frac{KWH/year}{ft^2})_M$ are known for this year a simple computation from Equation (3) yields the value $(\frac{KWH/year}{\$})$ = 0.764 in 1970. This quantity is by no means constant over the period 1960-1970. A clue to the rate of growth of electrical energy per dollar of value added is given by the behavior of the demand for industrial energy in the years 1969 and 1970. Although value added by manufacture was virtually stationary (Table 3), $(KWH)_I$ climbed by about 5.7% from 1969 to 1970. By subtracting out the slight growth in the contribution to $(KWH)_I$ from lighting and convenience outlets one finds that the value of $(\frac{KWH/year}{\$})$ must have increased by about 6%. In order to account for this important effect approximately, a simple exponential function is postulated with an equivalent 4%/year growth rate over the period 1960-1970 as follows:

$$\left(\frac{KWH/year}{\$}\right) = 0.764 \exp \left[ 0.04 \ (Y - 1970) \right]$$

where Y is the year A.D. The estimated values of $(\frac{KWH/year}{\$})$ so calculated are given in Table 3.

Finally, the estimated values of $(KWH)_I$ are calculated from Equation (3), and compared in Table 3 with the actual values of $(KWH)_I$ obtained from the statistical data in References 2 and 3. Also listed in Table 3 are the first differences $[\Delta(KWH)_I]_{ACTUAL}$ and $[\Delta(KWH)_I]_{CALCULATED}$. Figure 3 illustrates the time history of V, $\Delta$V, $S_M$, and $(KWH)_I$ over the time period 1960-1970. The agreement between calculated and actual values of $(KWH)_I$ is generally satisfactory, but there is some indication that the estimated $(\frac{KWH/year}{\$})$ is somewhat too low in the period 1960-1962. Also the response of the calculated $(KWH)_I$ to the upswing in value added by manufacture in the period 1965-1967 is somewhat greater than the response of the actual $(KWH)_I$. Over the time period 1961-

1967 the equivalent exponential rate of growth of $(KWH)_I$ is about 7.5%/year, of which about 6%/year is contributed by the growth in value added by manufacture plus the growth in $(\frac{KWH/year}{\$})$. Over the last four years most of the increase in $(KWH)_I$ can be attributed to the increase in electrical energy per dollar of value added.

A better check on the two-parameter correlation given by Equation (3) could be made by obtaining actual data on $(\frac{KWH/year}{\$})$ over the entire decade 1960-1970, and by examining the industrial processes in some detail in order to understand the reasons for the increased use of electrical energy per dollar of value added by manufacture. A more complete picture must also include the time history of natural gas and oil consumption in manufacturing plants in the South Coast Air Basin. It would be interesting to extend this study to the rest of the post WW II period 1945-1960.

# 4 COMPARISON BETWEEN PROJECTED ELECTRICAL ENERGY DEMAND AND ELECTRICAL GENERATING CAPACITY

## *4.1 Forecasting Future Demand for Commercial and Industrial Electrical Energy*

By utilizing the functional relations given by Equations (1) and (3) we can make forecasts of future demand for commercial and industrial electrical energy in the South Coast Air Basin, based on "reasonable" projections of the driving economic parameters. Two projections of commercial electrical energy demand are shown in Figure 4. The "minimum" growth forecast [labelled 1] is based on the assumption of an increase in commercial floor area by a constant amount of 36.5 $Mft^2$/year—the estimated $\Delta S_c$ for 1971 (Table 1). The electrical loading is allowed to increase at an equivalent exponential rate of 1%/year from its 1969 value of 25.7 $(\frac{KWH/year}{ft^2})$. Over the period 1970-1990 this "minimum" growth projection amounts to an equivalent exponential growth rate of about 4.6%/year in commercial electrical energy use.

The "maximum" growth forecast [labelled 2 in Figure 4] assumes that commercial floor area will increase at an equivalent exponential rate of 5%/year, while electrical loading increases at 2%/year. As shown by Equation (1) $(KWH)_c$ increases by 7%/year in this case.

Two projections of industrial electrical energy demand are shown in Figure 5. The "minimum" growth projection assumes a modest growth rate of 2%/year in value added by manufacture, in kilowatts/year per dollar of value added, in manufacturing floor space, and in $(\frac{KWH/year}{ft^2})_M$. According to Equation (3) this projection amounts to an equivalent exponential growth rate of 4%/year in $(KWH)_I$. The "maximum" growth projection [labelled 2] is based on a more vigorous rate of expansion of 4%/year in V and in KWH/year per dollar, but retains the assumption of 2%/year growth rate in $S_M$ and in $(\frac{KWH/year}{ft^2})_M$. Over the period 1970-1986 this "maximum" growth projection amounts to an equivalent exponential growth rate varying from about 6 2/3% to 8% per year.

Numerous studies have been made in recent years of the probable future growth in residential electrical energy demand, including investigations by the Caltech Environmental Quality Laboratory (1970, unpublished) and by the RAND Corporation (Reference 1). These studies indicate that the growth in residential demand over the next 15-20 years should fall between a "saturation", or "minimum" growth rate of about 5%/year and its present growth rate of about 8%/year. All other categories (agricultural, public authorities, miscellaneous) are also growing at present at about 8%/year. It seems reasonable to suppose that total yearly demand for electrical energy in the South Coast Air

Basin will grow at a rate lying somewhere between 5%/year and 7%/year over the next 15-20 years, although respectable arguments can certainly be made for a slightly higher maximum growth rate and a slightly lower minimum growth rate. This estimated maximum growth rate should be compared with the equivalent rate of 8.5%/year over the period 1960-1969.

### *4.2 Comparison Between Total Demand and Electrical Generating Capacity*

Because of obvious differences in the planned schedules for new electrical generating capacity for the Los Angeles Department of Water and Power and the Southern California Edison Company, a meaningful comparison between demand and capacity has to be made separately for each utility. Figure 6 shows the projected net system peak in megawatts at growth rates of 5%/year and 7%/year in the period 1970-1982. Also shown for comparison is a "conservative" estimate of the expansion in generating capacity in this period. By "conservative" we mean that only those units that have a high probability of actually going "on line" are included in the comparison. For example, in view of the recent unanimous decision of the California Supreme Court in the case of Orange County Air Pollution Control District v. Public Utilities Commission, the proposed Huntington Beach expansion is not included. No new units in the Four Corners area are shown in Figure 6, nor is the proposed coal-fired plant on the Kaiparowits Plateau included. On the other hand, the proposed pumped-storage plant at Black Star Canyon, and the Hi-Desert natural gas and oil-fired plants at Coolwater (expansion) and Fry Mountain are included as highly probable additions.

Because of the possibility of outages combined with unusual weather conditions, a reserve capacity of about 20% is considered to be a minimum satisfactory margin by SCE. According to the camparison shown in Figure 6, if the growth rate in demand is actually 7%/year the SCE reserve capacity will decline to about 15% by 1975, will rise to about 20% by 1978, and will decline again to about 10% by the end of the decade. Any serious delays in bringing San Onofre units #2 and #3 on line will result in an earlier shrinkage in reserve margin.* On the other hand, at the "minimum" projected growth rate of 5%/year the 20% reserve requirement is met over the whole decade.

In Figure 7 a comparison of supply and demand is shown for the Los Angeles Department of Water and Power. Reserve capacity for this system is about 22% in 1977 if the growth rate in demand is 7%/year. By 1978 the reserve shrinks to 15%, by 1979 it

---

* In August, 1971, SCE announced a delay in the development of these units pending an analysis of new reactor safety and earthquake-induced ground motion criteria.

is 10% and by 1980 it is about 6%. Again, if the minimum growth projection of 5%/year should be realized the reserve margin is adequate over the whole decade.

Certain short-term measures can be taken to deal with this situation. For example:

(1) Installation of gas turbine peaking units with a generating capacity of about 120 MW(e) each. Four such units have already been placed in operation at SCE plants. Delivery on these units is estimated at 18 months to two years.

(2) "Wheeling" of electric power from Northern California (Pacific Gas and Electric Company) and the Pacific Northwest (Bonneville).*

(3) Initiation of an electrical energy conservation program similar to the SAVE–A–WATT campaign of Con Ed (N.Y.).

(4) Preparation of plans for reduction in voltage and interruption of service to selective categories and areas during winter and summer peaks.

These measures are barely adequate for the 1970's, and with the exception of (3), certainly unsatisfactory for the 1980's. Some of the long-range implications of the growing demand for electrical energy in the South Coast Air Basin are discussed in the next section.

---

* Toward the middle to the end of the decade this option may vanish because of shrinking reserve capacity.

# 5 LONG-RANGE IMPLICATIONS OF THE GROWING DEMAND FOR ELECTRICAL ENERGY

A combination of environmental, land use and technological factors is forcing us to develop a new strategy to cope with the demand-supply situation for electrical energy in the South Coast Air Basin. On the supply side the famous "law of compound interest" has finally caught up with us. By 1961 a growth rate of 8.5%/year in demand, plus a replacement rate of old equipment of 1.5%/year, meant that SCE had to add about 500 MW(e) of new generating capacity each year in order to maintain a reserve of 20% of total capacity.* In 1961 this requirement was met by adding Huntington Beach Unit #4 and Alamitos Unit #3 [550MW (e).] By 1966 additional capacity of about 750 MW(e)/year was needed, and this new capacity was provided by adding Alamitos Units #5 and #6 [960 MW(e)] in that year.

By 1970 the rate of expansion in generating capacity required for SCE alone had reached a level of about 1000 MW(e)/year, and by 1975, even with a reduced growth rate in demand of 7%/year, the additional capacity needed is estimated to be about 1200 MW(e)/year.** However, stringent air quality standards make it virtually impossible to build new fossil-fuel power plants or to expand existing ones in the Basin [ except for Ormond Beach, currently under construction in Ventura County (Figure 6)] .*** Recognizing these restrictions, L.A. DWP and SCE sought new generating capacity outside the Basin, but now serious controversy has erupted over air pollution produced by the existing coal-fired plants in Nevada and New Mexico, and over the strip-mining that supplies these plants with coal. It is quite possible that no new fossil-fuel plants will be built in the desert after Mohave and Navajo are completed (Figures 6 and 7).

What about nuclear power plants? Coastal sites for nuclear power plants that meet geological criteria and are also remote from centers of high population density are scarce in Southern California, and the very few sites satisfying these requirements do not always meet with universal acclaim. Moreover, for excellent reasons, new nuclear power plant units are presently "quantized" at 1150 MW(e). This figure is barely adequate as a yearly addition rate to generating capacity in 1976, when San Onofre #2 will go "on line". It is certainly inadequate for 1980, when the yearly rate of expansion in capacity required reaches 1650 MW(e) (Figure 6).

* 8.5% x 1.25 = 10.65%; adding the 1.5% replacement rate means that the required rate of addition to capacity is 12.2%/year.

** The reduced rate of expansion in capacity is about 10%/year.

*** Large gas-turbine peaking power units of about 120 MW(e) each do meet the requirements of not more than 140 pounds/hour nitrogen oxide emissions from any one unit.

"Interim solutions" for the period from the late 1970's to mid-1980's could alleviate this situation if these solutions are set in motion promptly in the early 1970's. One solution is a large nuclear power plant at Point Conception. Another solution involves *inland* siting of *nuclear* power plants using either "dry" cooling towers or wet evaporative cooling towers. If the latter type of cooling system is employed at least three main possibilities come to mind:

(1) By utilizing the water rights from Lake Powell already granted for a proposed 6000 MW(e) coal-fueled power plant on the Kaiparowits Plateau (Utah), a 4000 MW(e) light water nuclear power plant could be built in the same general location.

(2) As the reuse of reclaimed municipal waste water increases in the South Coast Air Basin and water from the California Aqueduct becomes available, the possibility of using the low-quality Colorado River or Colorado Aqueduct water in evaporative cooling towers is opened up. For example, the 117,000 acre-feet/year now allocated to the L.A. DWP could be utilized for a 4000 MW(e) nuclear power plant along the Colorado River or the Colorado Aqueduct.

(3) Reclaimed municipal waste water or reclaimed agricultural waste water could be piped directly to inland nuclear power plants.

These "interim solutions", helpful as they are, will not cope with the long-term demands for electrical energy in the South Coast Air Basin. If a growth rate in demand of 7%/year is in fact maintained over the whole period 1970-1985, then by 1985 the required rate of expansion in generating capacity for the *combined* Los Angeles Department of Water and Power and SCE system will be about 3200 MW(e)/year. By 1990 this figure is 4400 MW(e)/year. By comparison, if a growth rate of 5%/year is maintained from 1975 on (for example), the required additional generating capacity is about 2100 MW(e)/year in 1985 and about 2600MW(e)/year in 1990.* Entirely new concepts of power plant siting and construction are required, including off-shore siting (floating or on islands) and underground siting.** Off-shore siting, in particular, may offer the advantage of standardized, shipyard construction for the replication of nuclear generating stations at the required annual rates and at acceptable cost.

On the *demand* side there is agreement in most quarters that the days of

---

* The required rate of expansion in capacity would be about 8%/year in this case.

** A Task Force on Novel Methods of Nuclear Power Plant Siting has been set up within the Caltech Environmental Quality Laboratory.

"uncontrolled" growth in the use of electrical energy are over. But there is no general agreement as yet on the best tools that should be used to control growth, largely because this problem is novel and complex. To borrow a useful concept from the fields of air and water pollution, one might adopt as a "management standard" a rate of growth in the use of electrical energy not to exceed 5%/year by 1976 [ See Figures 6 and 7 ]. This management standard could be achieved by pricing, by taxation, by regulation, or by combinations of all three policies [ Figure 1 ].

At first glance the pricing mechanism seems to be too blunt an instrument to control growth in demand, because the cost of electrical energy at present is such a small fraction of total costs. For example, an "all-electric" commercial building containing 1M square feet of floor area costs roughly $30M to build, and utilizes about 44M KWH/year at a cost of about $780,000/year. But payment of principal and 10%/year compound interest on investment amounts to $8.1M/year on the basis of a ten-year payout period; property taxes (allowing for depreciation) are about $1.5M/year, and maintenance and upkeep are about $0.4M/year. Thus, the cost of electrical energy is less than 8% of required rental income. Under the present tax laws modest increases (15%–25%) in electric power rates probably are not going to have much effect on the attractiveness of all-electric, high-rise buildings as a capital investment.*

No one knows how to predict the effect that *substantial* increases in electrical energy costs would have in slowing down the rate of growth in demand. We should keep in mind that the "management standard" suggested here does not call for stopping growth altogether, but for reducing the rate of growth in the demand for electrical energy from its 1970 level of 7.5%/year to 5%/year. For example, commercial customers might pay a base rate of 1.8¢/KWH for electrical loadings up to 15KWH/year/ft$^2$, but the portion of electrical loading in excess of this figure could be billed at triple the base rate. Or, as Dr. Burton H. Klein, the Caltech economist, has suggested, commercial customers might pay an environmental protection tax when they are connected to the mains. The proceeds from this tax would be utilized to reduce the environmental impact of the growing demand for electrical energy. Alternatively, as suggested by Dr. Charles Plott, also of Caltech, we might allow the price of electric power to the consumer to "float" freely, so that the utilities themselves would have to take environmental costs into account. Finally, one might utilize the regulatory powers contained in the issuance or withholding of building permits to control the growth rate, and/or to stimulate new construction technology that

---

* Roughly speaking, allowance for rapid depreciation at the rate of 10%/year almost wipes out income tax liability on rental income. To borrow a phrase from Theo von Kārmān, this brief discussion is a "cavalier" treatment of a highly complex subject.

would slow down the rate of growth in electrical loading (Section 2).

The problem of controlling the rate of growth in demand for electrical energy in the industrial sector is even more complex (Section 3). It involves the rate of growth of the labor force and its distribution between manufacturing, trade and services; the rate of substitution of electrical energy for labor; the length of the work-week, etc. The problem is further complicated by the urgent necessity of providing sufficient electrical energy for pollution control and environmental improvement activities. Obviously, the present report raises as many questions as it answers. It is only the beginning of an inquiry into the quantitative relations between the permissible rate of economic expansion and the rate of growth in the use of electrical energy, as constrained by environmental, land use, economic and technological factors.

## *REFERENCES*

1. Anderson, Kent P., "The Demand for Electricity in California –– Dimensions of Future Growth." RAND Corporation Working Note #WN-7550-NSF, August, 1971 (Santa Monica, Calif.)

2. Los Angeles Department of Water and Power: (a) Official Statement, $39 M Electric Plant Revenue Bonds, Fourth Issue of 1970, November 19, 1970, pp. 16-17; (b) Annual Reports, Board of Water and Power Commissioners, 1960–1961 through 1969–1970.

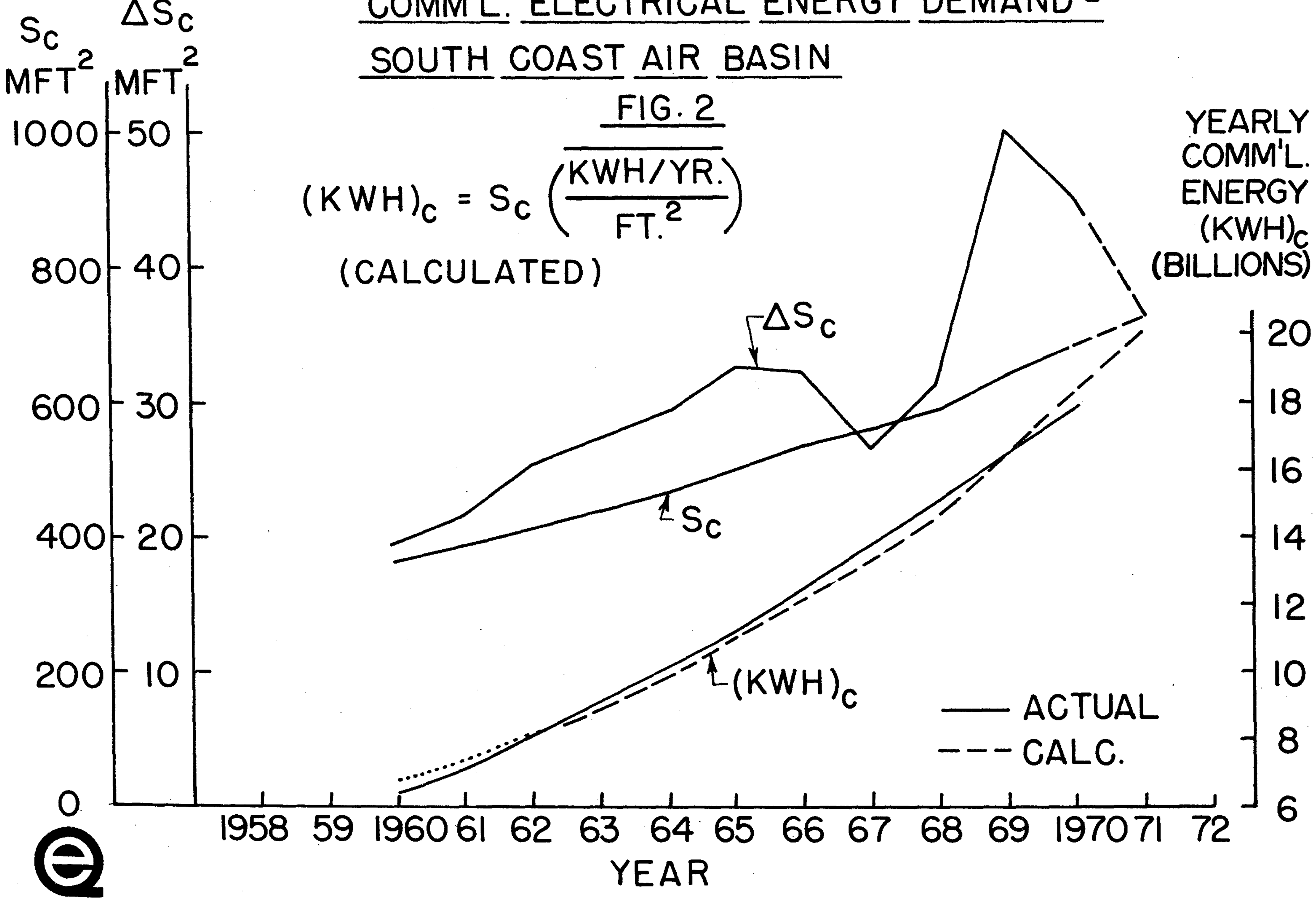
3. Southern California Edison Company: (a) 1969 and 1970 Financial and Statistical Reports; (b) Annual Reports for years 1961 through 1965.

4. "1967 Census of Manufactures for California," issued March, 1970 by the Bureau of The Census, U.S. Department of Commerce, Washington, D.C.

5. United California Bank, Los Angeles, California, Research and Planning Division, "1971 Forecast."

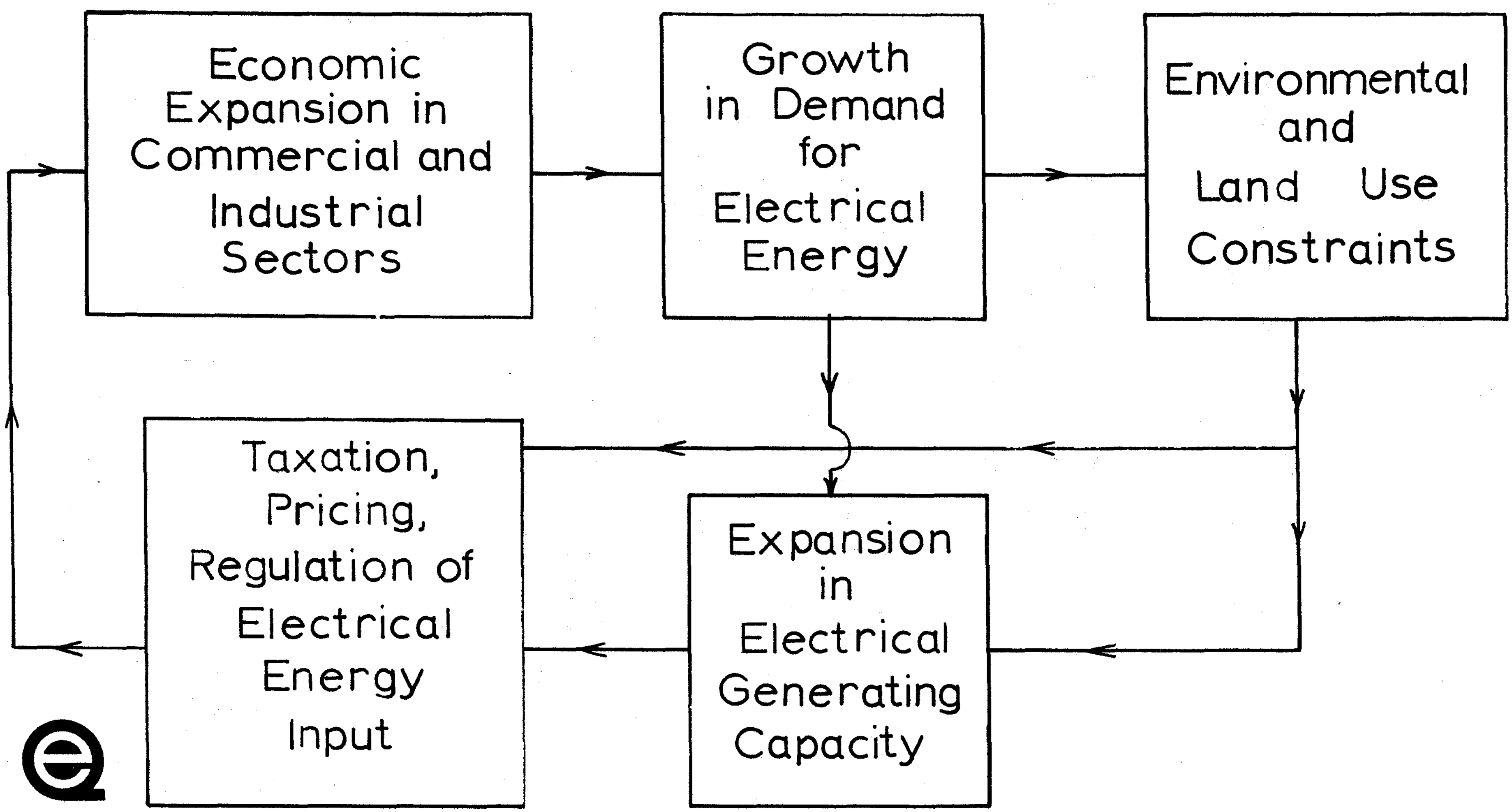
GROWTH IN COMMERCIAL FLOOR AREA AND COMM'L. ELECTRICAL ENERGY DEMAND - SOUTH COAST AIR BASIN

FIG. 2



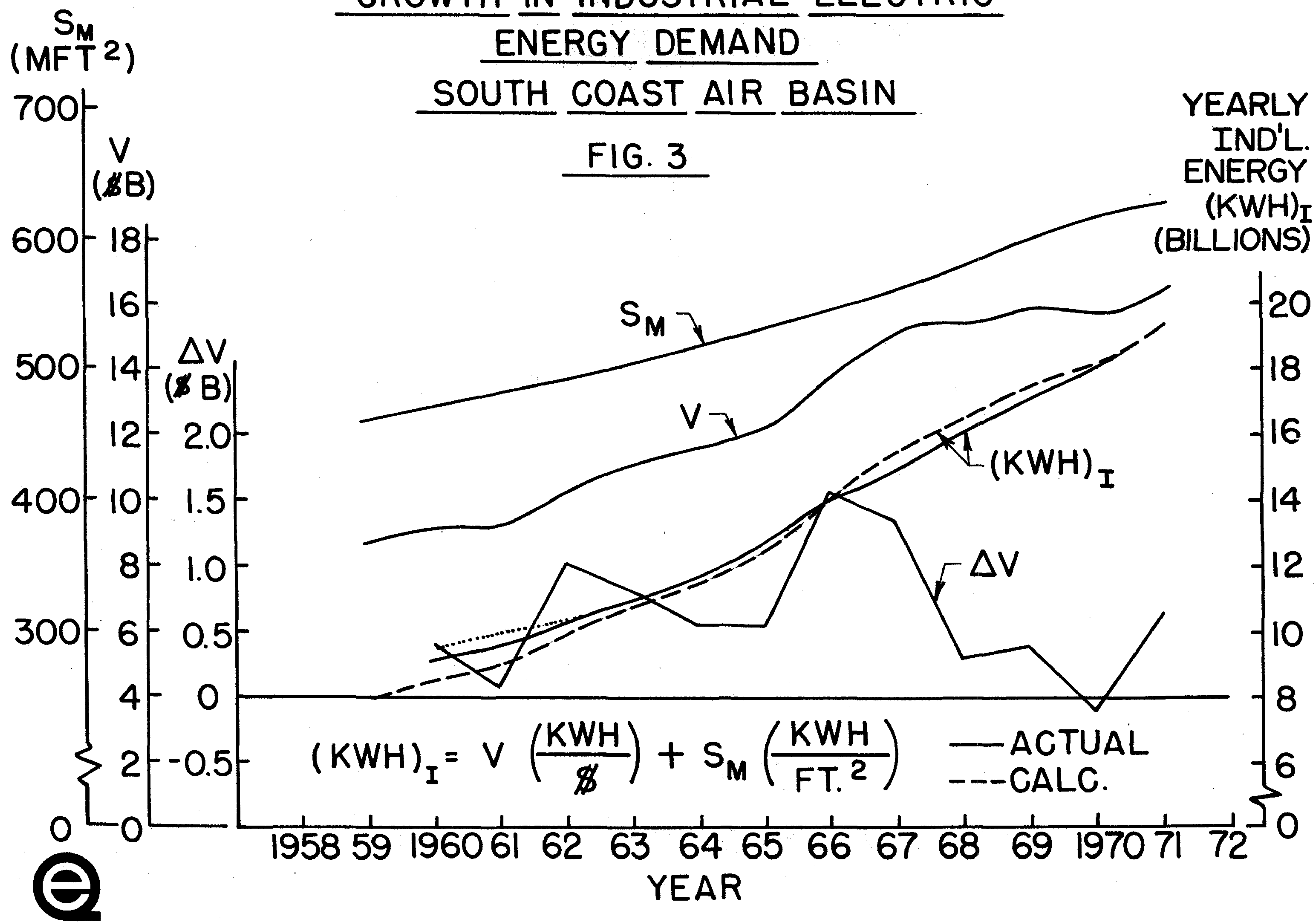
## SCHEMATIC OF SIMPLEST ELECTRICAL ENERGY FEEDBACK LOOP

FIG. 1

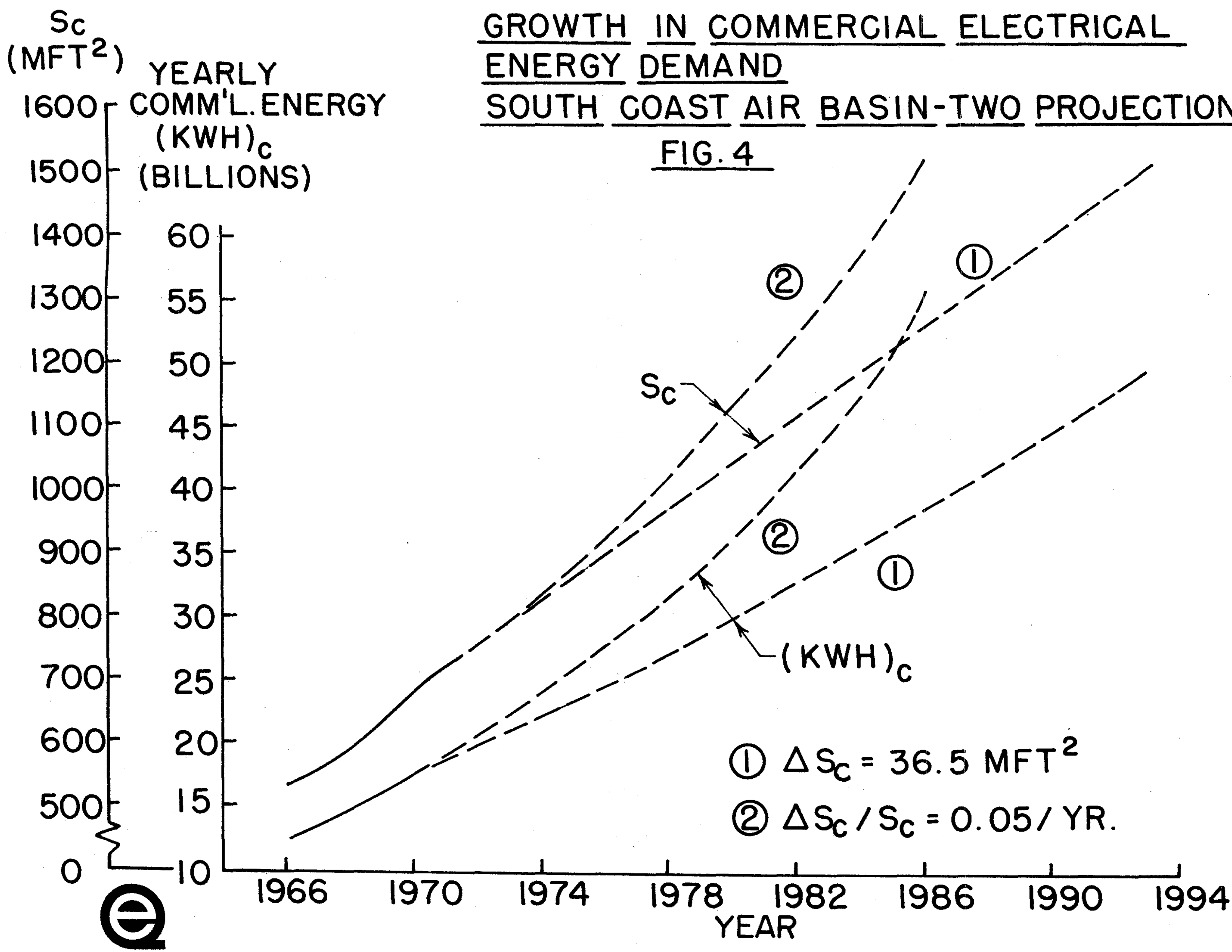


## GROWTH IN INDUSTRIAL ELECTRIC ENERGY DEMAND SOUTH COAST AIR BASIN

FIG. 3



GROWTH IN COMMERCIAL ELECTRICAL ENERGY DEMAND
SOUTH COAST AIR BASIN-TWO PROJECTIONS
FIG. 4

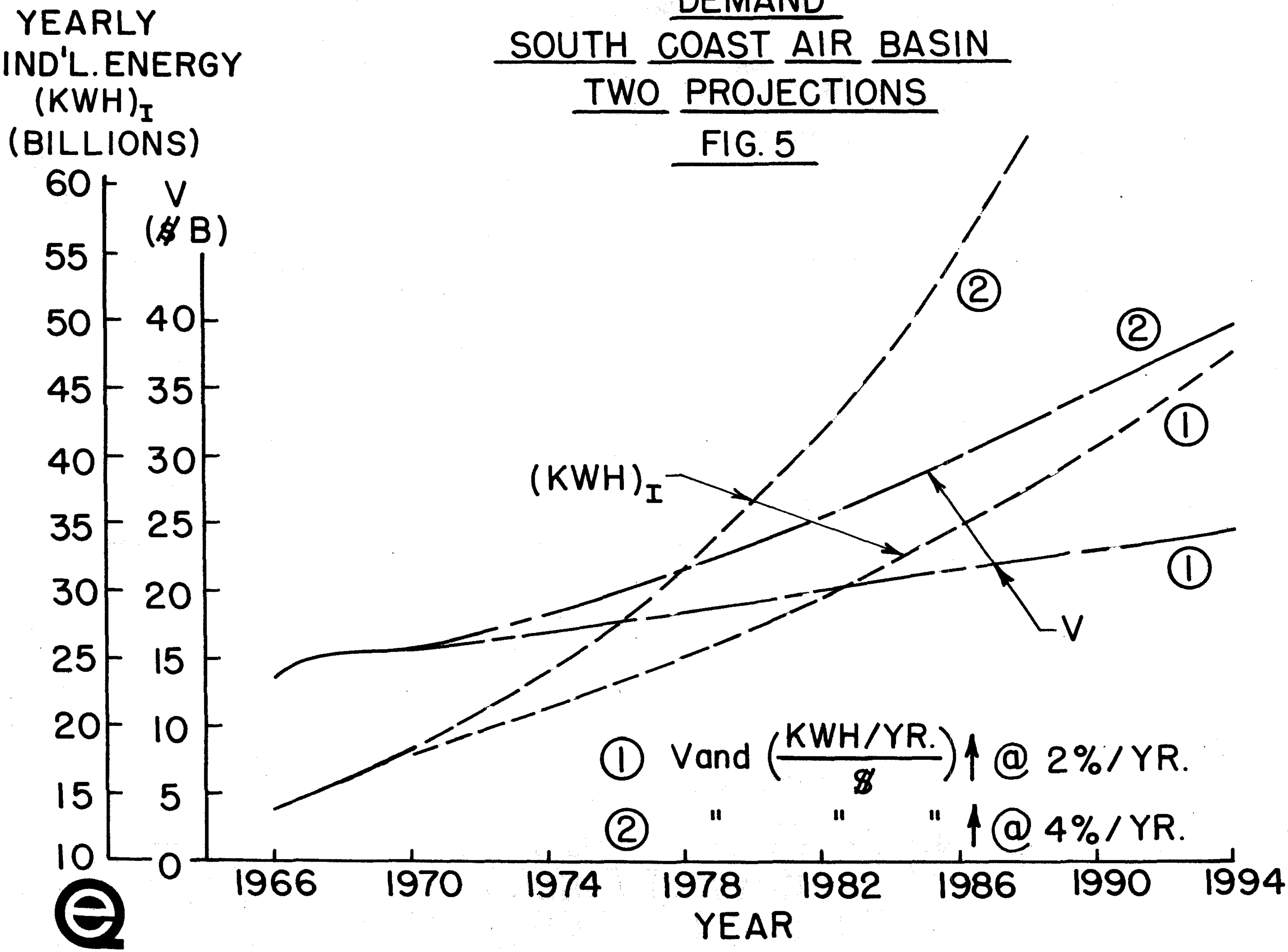


GROWTH IN INDUSTRIAL ELECTRICAL ENERGY DEMAND

SOUTH COAST AIR BASIN

TWO PROJECTIONS

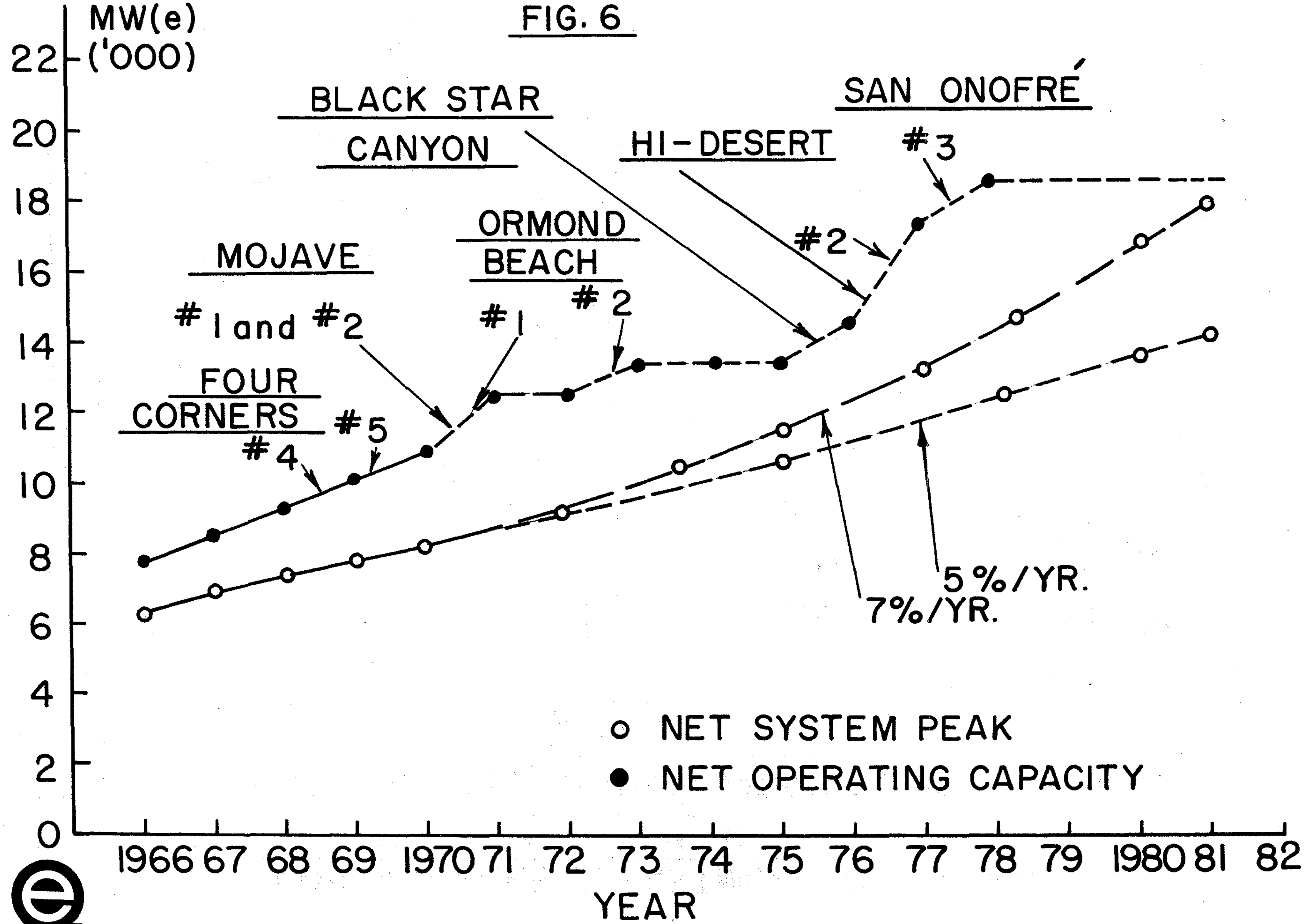
FIG. 5



SOUTHERN CALIFORNIA EDISON CO.

PROJECTED GENERATING CAPACITY AND DEMAND

FIG. 6



LOS ANGELES DEPARTMENT OF WATER AND POWER
PROJECTED GENERATING CAPACITY AND DEMAND

FIG. 7

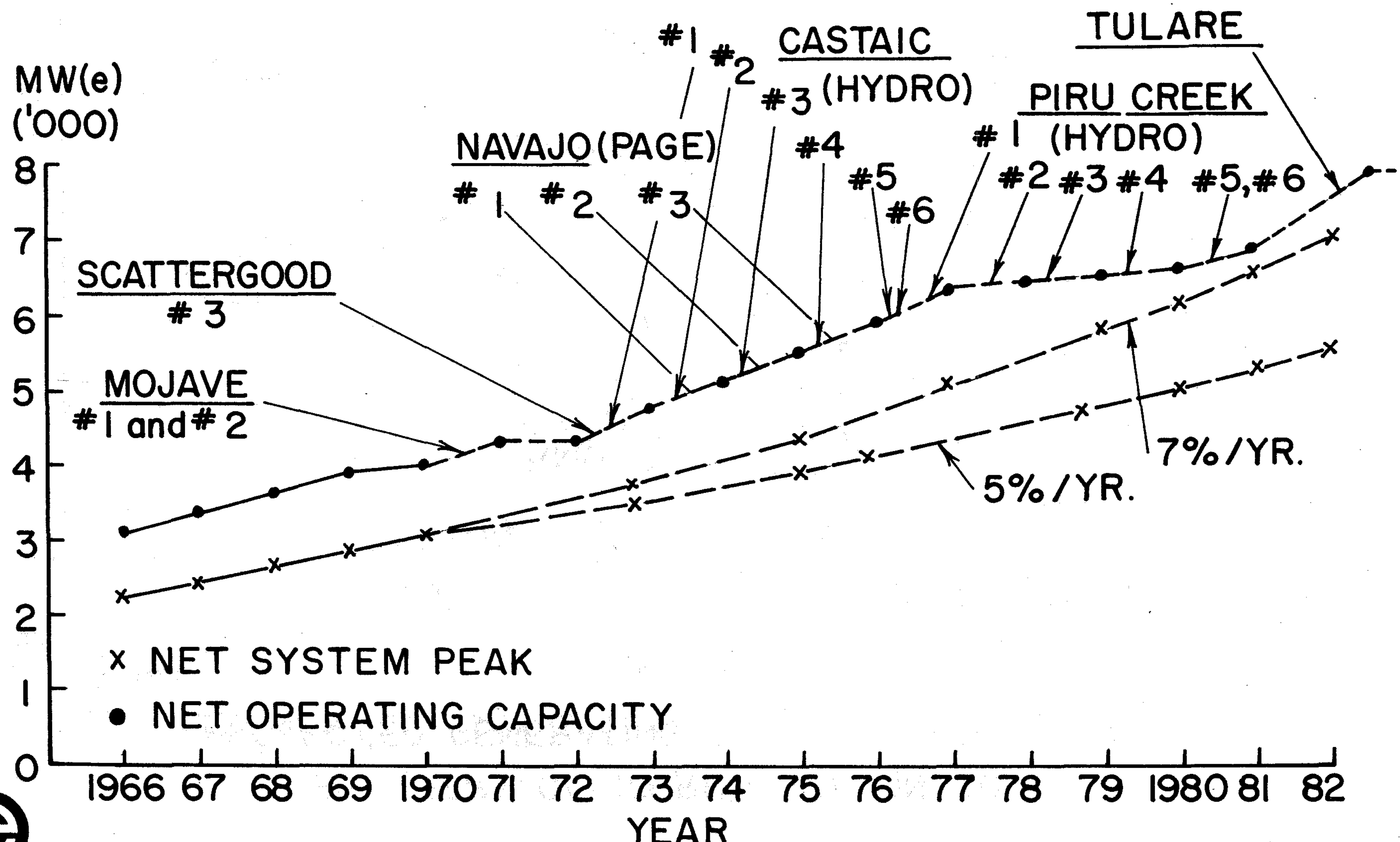


**TABLE 1**

Growth in Commercial Floor Area in the South Coast Air Basin

| ITEM \ YEAR | 1971 (est.) | 1970 | 1969 | 1968 | 1967 | 1966 | 1965 | 1964 | 1963 | 1962 | 1961 | 1960 | 1959 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total non-residential building (M $ft^2$) | 73 | 86 | 105 | 79 | 70 | 83 | 77 | 73 | 68 | 63 | 61 | 56 | |
| % Commercial building (Region VIII) | 50 | 52 | 48 | 40 | 38.4 | 39 | 42.5 | 39.6 | 40 | 36 | 35.5 | 34.8 | |
| Commercial building (M $ft^2$) $\Delta S_c$ | 36.5 | 45 | 50 | 31.3 | 26.7 | 32.2 | 32.8 | 29.2 | 27.2 | 22.9 | 21.5 | 19.5 | |
| Commercial floor area (M $ft^2$) $S_c$ | 722 | 685 | 640 | 590 | 559 | 532 | 500 | 467 | 438 | 411 | 388 | 366 | 346 |

## TABLE 2

Commercial Energy Demand in the South Coast Air Basin

| ITEM \ YEAR | 1971 (est.) | 1970 | 1969 | 1968 | 1967 | 1966 | 1965 | 1964 | 1963 | 1962 | 1961 | 1960 | 1959 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $S_c$ M $ft^2$ (from table 1) | 722 | 685 | 640 | 590 | 559 | 532 | 500 | 467 | 438 | 411 | 388 | 366 | 346 |
| $\left(\frac{KWH/year}{ft^2}\right)$ | 27.8 | 26.7 | 25.7 | 24.7 | 23.8 | 22.9 | 22.0 | 21.2 | 20.3 | 19.5 | 18.8 | 18.0 | 17.3 |
| $(KWH)_c$ calculated (BILLIONS) | 20.7 | 18.30 | 16.42 | 14.60 | 13.3 | 12.2 | 11.0 | 9.9 | 8.9 | 8.03 | 7.30 | 6.60 | 6.0 |
| $(KWH)_c$ actual (BILLIONS) SCE | | 10.12 | 9.21 | 8.27 | 7.55 | 6.76 | 5.94 | 5.36 | 4.74 | 4.21 | 3.81* | 3.43* | |
| LADWP | | 7.63 | 7.21 | 6.77 | 6.22 | 5.71 | 5.25 | 4.79 | 4.33 | 3.98 | 3.56 | 3.31 | |
| TOTAL | | 17.75 | 16.42 | 15.04 | 13.77 | 12.47 | 11.19 | 10.15 | 9.07 | 8.19 | 7.37* | 6.74* | |
| $\Delta$ $(KWH)_c$ calculated (BILLIONS) | 1.80 | 1.88 | 1.82 | 1.30 | 1.10 | 1.20 | 1.10 | 1.00 | 0.87 | 0.73 | 0.70 | 0.60 | |
| $\Delta$ $(KWH)_c$ actual (BILLIONS) | | 1.33 | 1.38 | 1.27 | 1.30 | 1.28 | 1.04 | 1.08 | 0.88 | 0.82 | 0.63 | | |

* The figures shown for 1960 and 1961 are the combined commercial electrical energy for both SCE and California Electric (dotted line in Figure 2); the figures for SCE alone for these years are 3.14B and 3.52B, respectively, and the corresponding totals are 6.45B and 7.08B, respectively (solid curve in Figure 2).

**TABLE 3**

Industrial Energy Demand in the South Coast Air Basin

| ITEM / YEAR | 1971 (est.) | 1970 | 1969 | 1968 | 1967 | 1966 | 1965 | 1964 | 1963 | 1962 | 1961 | 1960 | 1959 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value added by manufacture V ($B) | 16.40 | 15.73 | 15.80 | 15.4 | 15.1 | 13.75 | 12.20 | 11.65 | 11.08 | 10.25 | 9.22 | 9.14 | 8.72 |
| $\Delta V$ ($B) | +0.67 | -0.07 | +0.40 | 0.3 | 1.35 | 1.55 | 0.55 | 0.57 | 0.83 | 1.03 | 0.08 | 0.42 | |
| $\Delta S_M$ (M ft²) | 12 | 15 | 22 | 18 | 14 | 17 | 12 | 13 | 11 | 12 | 10 | 10 | |
| $S_M$ (M ft²) | 627 | 615 | 600 | 578 | 560 | 546 | 529 | 517 | 504 | 493 | 481 | 471 | 461 |
| $\left(\frac{KWH/year}{ft^2}\right)_M$ | 10 | 10 | 9.8 | 9.6 | 9.4 | 9.2 | 9.0 | 8.8 | 8.7 | 8.5 | 8.3 | 8.1 | 8.0 |
| $\left(\frac{KWH/year}{\$}\right)$ | 0.796 | 0.764 | 0.735 | 0.705 | 0.68 | 0.65 | 0.63 | 0.60 | 0.58 | 0.56 | 0.54 | 0.51 | 0.49 |

TABLE 3 (continued)

| ITEM \ YEAR | 1971 (est.) | 1970 | 1969 | 1968 | 1967 | 1966 | 1965 | 1964 | 1963 | 1962 | 1961 | 1960 | 1959 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $(KWH)_I$, calculated (BILLIONS) | 19.37 | 18.17 | 17.48 | 16.43 | 15.52 | 14.01 | 12.45 | 11.55 | 10.80 | 9.94 | 8.98 | 8.49 | 7.97 |
| $(KWH)_I$, actual (BILLIONS) SCE | | 14.96 | 14.13 | 13.43 | 12.49 | 11.75 | 10.54 | 9.71 | 8.92 | 8.37 | 8.23 | 7.81 | (See Footnote Table 2) |
| LADWP | | 3.21 | 3.06 | 2.73 | 2.49 | 2.38 | 2.20 | 2.05 | 1.97 | 1.92 | 1.80 | 1.73 | |
| TOTAL | | 18.17 | 17.19 | 16.16 | 14.98 | 14.13 | 12.74 | 11.76 | 10.89 | 10.29 | 10.03 (9.59) | 9.54 (9.10) | |
| $\Delta$ $(KWH)_I$, calculated | 1.20 | 0.69 | 1.05 | 0.91 | 1.51 | 1.56 | 0.90 | 0.75 | 0.86 | 0.96 | 0.49 | | |
| $\Delta$ $(KWH)_I$, actual | | 0.98 | 1.03 | 1.18 | 0.85 | 1.39 | 0.98 | 0.87 | 0.60 | 0.26 (0.70) | 0.49 (0.49) | | |

## APPENDIX A

Total Non-Residential Building – Major Marketing Areas in M $ft^2$

<table>
<tr><th>YEAR / ITEM</th><th>1971 (est.)</th><th>1970</th><th>1969</th><th>1968</th><th>1967</th><th>1966</th><th>1965</th><th>1964</th><th>1963</th><th>1962</th><th>1961</th><th>1960</th></tr>
<tr><td>Anaheim–Santa Ana–Garden Grove (Orange Co.)</td><td>10.30</td><td>17.00</td><td>19.74</td><td>14.14</td><td>13.02</td><td>14.35</td><td>14.58</td><td>13.21</td><td>11.47</td><td>11.74</td><td>9.14</td><td>9.74</td></tr>
<tr><td>Bakersfield</td><td>1.36</td><td>1.23</td><td>1.81</td><td>1.30</td><td>1.39</td><td>2.08</td><td>2.02</td><td>1.83</td><td>1.13</td><td>0.97</td><td>1.08</td><td>1.47</td></tr>
<tr><td>Los Angeles–Long Beach</td><td>52.00</td><td>59.00</td><td>71.11</td><td>50.91</td><td>44.36</td><td>51.99</td><td rowspan="2">48.53</td><td rowspan="2">46.97</td><td rowspan="2">47.14</td><td rowspan="2">42.67</td><td rowspan="2">43.07</td><td rowspan="2">37.99</td></tr>
<tr><td>Oxnard–Ventura</td><td>3.10</td><td>1.67</td><td>2.77</td><td>2.08</td><td>2.94</td><td>3.60</td></tr>
<tr><td>Riverside</td><td>1.84</td><td>2.84</td><td>4.17</td><td>5.53</td><td>4.43</td><td>4.99</td><td>3.73</td><td>3.93</td><td>2.79</td><td>2.49</td><td>3.01</td><td>2.03</td></tr>
<tr><td>San Bernardino</td><td>3.58</td><td>3.40</td><td>1.70</td><td>2.15</td><td>1.99</td><td>2.58</td><td>5.87</td><td>5.17</td><td>3.38</td><td>3.48</td><td>2.71</td><td>2.94</td></tr>
<tr><td>Santa Barbara</td><td>0.78</td><td>0.90</td><td>4.13</td><td>2.62</td><td>1.41</td><td>2.93</td><td>2.64</td><td>2.28</td><td>2.14</td><td>2.06</td><td>1.77</td><td>1.85</td></tr>
<tr><td>TOTAL</td><td>72.96</td><td>86.04</td><td>105.43</td><td>78.73</td><td>69.54</td><td>82.52</td><td>77.27</td><td>73.39</td><td>68.05</td><td>63.41</td><td>60.78</td><td>56.02</td></tr>
<tr><td>Mfg. as % of total non-res. bldg. (Region VIII)</td><td>16.1</td><td>17.4</td><td>21</td><td>23</td><td>20</td><td>21</td><td>16</td><td>18</td><td>16</td><td>19</td><td>17</td><td>17</td></tr>
</table>