# TRENDS IN RESIDENTIAL APPLIANCE EFFICIENCY CHOICE

Michael R. Jaske
California Energy Commission

## ABSTRACT

This paper presents preliminary results of an extensive survey of single family residences in Northern California in which the efficiency characteristics of residential appliances were the principal data objectives. Analysis of the data to date reveals interesting trends in the marginal efficiency choices made by year of purchase. Individual appliance and sub-appliance product class variations are considerable. For example, the overall refrigerator end use efficiency increases are substantial, led by the top freezer product class, yet the side-by-side product class gained relatively little. No significant improvements are noted for gas central furnaces or gas water heaters in the most recent vintage of sales. Further analysis of this data for causality could lead to significant improvements in current forecasting models using either explicit discrete choice or implicit fuel price elasticity formulations for efficiency improvement. Appliance efficiency conservation programs -- standards, tax credits, subsidies, information -- could be better designed and operated as a result of this research on basic consumer choice.

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## INTRODUCTION

Consumer purchase of white good durables is a major factor governing the marginal energy efficiency of all capital goods entering the economy. State [1] and federal energy policies [2,3] since the mid-1970s have attempted to encourage the purchase of higher efficiency models. Recently, utilities have begun incentive programs [4] aimed at a few appliances. All of this program activity supplements potential consumer response to high and rising energy prices in the face of a large technological potential for increased efficiency. The nature and extent of consumer choice of higher efficiency appliance models is poorly understood, in large part due to the paucity of data characterizing efficiency purchases. This paper describes preliminary results of a large scale residential survey of single family housing in Northern California for the explicit purpose of understanding appliance efficiency choice, both past and present.

### Motivation

Collection of data from the individual utility customers is but one facet of several activities undertaken recently by the California Energy Commission (CEC) in the appliance field. A major effort has been mounted in the U.S. Department of Energy (DOE) regulatory arena [5] and the federal courts [6] to defend California's Title 20 Appliance Standards. Most readers are familiar with DOE's "no standard" standards that threaten to preempt California, and all other state, standards regulating minimum permissable efficiency. The CEC has also entered into a rulemaking proceeding (limited to refrigerators, freezers, and air conditioners) that may result in upgraded standards, or other alternate programs designed to save equivalent amounts of energy. These efforts continue in the direction that the CEC was propelled by its enabling legislation, to "Prescribe, by regulation, standards for minimum levels of operating efficiency, based on a reasonable use pattern, for all appliances..." §25402(c) Public Resources Code.

### The Data

The survey data discussed here was collected in June and July, 1983, by Pacific Gas and Electric Company (PGandE) Residential Conservation Service (RCS) auditors. Essentially all RCS audits during this period had supplemental appliance model data collected by the auditor in addition to his/her

*The author is Chief Energy Forecaster. All views expressed here are the author's and do not represent an official position of the California Energy Commission or the State of California.

normal duties. The survey forms and an extensive instruction package were prepared by CEC staff in April and May 1983 with the concurrence of PGandE headquarters RCS staff and management. Hard copy data were delivered by PGandE division offices to the CEC for analysis.

Brand name, manufacturer, model number, serial number, estimated year of purchase, and product type were collected for refrigerators, freezers, room air conditioners, central air conditioners, heat pumps, central gas furnaces, floor/ wall furnaces, and water heaters. In addition, persons per household by age group, dwelling square footage, annual household income, zip code, and the preceding year's utility billing history were obtained. Following a simple screening for plausibility, all forms admitted were keypunched. The data was converted to a Statistical Analysis System (SAS) data set for statistical analysis.

## Use of Results

Analysis of the data described here has been limited, and all results are preliminary. It is anticipated that the data will find several uses. First, it can provide an estimate of the average and the distribution of efficiencies in the stock for most appliances covered. Grouping the data into vintages can reveal changes in purchase patterns, either in average efficiency or in the distribution of efficiencies, over time. This data is not now available for any state, and only to a limited extent for the nation as a whole. Second, the data can provide a basis for quantitative attempts to correlate various explanatory factors with changes in efficiency over time. From such analysis may emerge some understanding of the process of "consumer choice", hopefully enough to revise current energy forecasting models [2,7,8] to refine the algorithms incorporating such factors in long run demand forecasts. Third, the data may lead to revised policy decisions on the part of the CEC in the mix of programs (standards, incentives, and education) that it wishes to pursue in its efforts to improve the efficiency of the California appliance stock.

## DATA COLLECTION AND PREPARATION

The raw data transmitted by PGandE RCS staff covered 3,857 Northern California housing units drawn from the entire service area. Simple screening of the forms prior to keypunching reduced the number of forms with any usable information to 3,706. PGandE auditors made only limited attempts to discover and record model numbers from name plates. This was consistent with the CEC/ PGandE agreement to avoid burdensome impacts on the basic RCS process. Of these 3,706 forms, much reduced numbers of models were actually identified. Table I summarizes the count of "model numbers" and unique "model numbers" by appliance. Many of these "model numbers" will never be identified as actual models due to a variety of omissions, transcription mistakes, and keypunch mistakes. However reduced, the magnitude of the task of identifying so many model numbers calls for setting priorities among vintages and appliances.

Preparation of the data for analysis has been accomplished in two steps: (1) keypunching and conversion of the survey data to a SAS data set, and (2) constructing efficiency, size, and year of assembly data for each model number and merging this data to the survey records. The first task is a very

straightforward one and will not be discussed here. Developing the needed characteristics for each model number is a far more complicated step.

The results described in this paper must be labeled preliminary precisely because many more models should be identified and characterized than those accomplished to date. Four general sources of information can be pursued in the search for model characteristics -- CEC certification files, direct assistance from manufacturers, catalogs published by major retailers, and other published literature. The first of these has been pursued vigorously, the second has been initiated, and the remaining sources have not yet been considered. This work is extremely labor intensive and requires the combination of personality features of dogged determination and an interest in detective work.

## CEC Certification Files

The CEC maintains a listing of appliance model numbers that are currently certified for sale in California. This is an important enforcement tool for the Title 20 Appliance Standards. Surveys [9] of retail showroom floors have found fairly high degrees of compliance with the standards (in the 95-98 percent range). Unfortunately, the focus on current models means that the data files are constantly updated and purged. Data for older models no longer in production may no longer be present even if the CEC once knew a great deal about the model in question. However, in general, this has been an excellent source of information for models built since 1978, providing efficiency data for many hundreds of models.

## Assistance From Manufacturers/Retailers

For individual manufacturers or major retailers with large numbers of older models that cannot be identified through CEC certification files, CEC staff have contacted a few to request assistance in this identification. Some information has been received but much remains unidentified.

## Other Sources

A few other sources may be of limited assistance in characterizing individual models. Major retailers such as Sears, Wards, and J.C. Penney may be able and willing to supply data about older models. Consumer organizations, such as Consumers Union, tests appliances and reports results in Consumer Reports. These sources have not yet been pursued.

## Merging Model Characteristics to Survey Data

Merging of data files was accomplished using SAS. Variants of true model numbers introduced by nonstandard transcription by PGandE auditors was accommodated by creating variants in the model characteristics file prior to merging. Again, this is a very labor intensive effort and has been pursued only to a limited extent. Finally, in those cases where the year of purchase estimated by the survey respondent disagrees with the year implied by decoding the model number, such discrepancies were resolved in favor of the manufacturer data.

Table I. Data Characteristics Summary.

| Appliance | Potential Model Numbers | Unique Model Numbers |
|---|---|---|
| Refrigerators/Freezers | 2513 | 2254 |
| Room Air | 76 | 73 |
| Central Air/Heat Pump | 413 | 386 |
| Water Heaters | 1671 | 1067 |
| Central Furnaces | 1276 | 1072 |
| Wall/Floor Furnaces | 226 | 202 |
| TOTAL | 6175 | 5054 |

Note: Table dated 1/20/84.

Table II reports current results of this process of data preparation. Among vintages the concentration upon the era of CEC standards has resulted in some success. Among appliance types, refrigerators have been concentrated upon with fairly good success.

Clearly a great deal more needs to be done to identify older models, especially if an understanding of the stock of appliances is desired.

## PRELIMINARY ANALYSIS OF THE DATA

The seven appliances covered in this project have encountered a variety of problems in the model characterization process. Four seem to have sufficient degrees of identification that preliminary statistics will at least exhibit reasonable behavior; these are refrigerators, freezers, central gas furnaces, and gas water heaters. This paper will report results exclusively for these appliances.

### Measure of Efficiency

Efficiency measures for each appliance used here are computed from the data available in CEC certification files. These are not necessarily the same as DOE efficiency measures, but the data conforms to DOE test procedures. For example, the DOE refrigerator measure is cubic feet/kilowatthour-day with the freezer volume inflated by 1.4 compared to the refrigerator volume. The CEC standard, and most available trade data, does not distinguish between these types of volumes. For this paper refrigerators and freezers are described in units of kWh/cuft-month with volume the simple sum of refrigerator and freezer space. Central furnaces are described in units of annual average percentage combustion efficiency. Water heaters are described in units of recovery combustion efficiency.

### Marginal Average Efficiency

Marginal additions to the appliance stock are commonly held to be significantly more efficient than the stock itself. Considerable dispute exists about the effective strength of the forces causing these increases. This paper attempts to describe what has actually occurred; little attention has yet been focused on attempts to explain either qualitatively or quantitatively why these changes have occurred. Table III displays the results of the preliminary analysis to date.

The three vintages displayed span a 9-year period. 1975-1977 corresponds to the era immediately preceding the CEC Title 20 Appliance Standards. 1978-1980 is a transition period when most CEC standards became effective and draft national standards were proposed. 1981-1983 is the most recent vintage. Because this survey data was collected in June-July 1983, some minor inaccuracy in 1981-1983 statistics may occur if 1983 additions are substantially better than those in 1981 and 1982. Examining the data on a year by year basis seems to indicate that this is not a significant problem.

Table II. Summary of Model Numbers Identified.

| End Use | Number of Models Reported | Number of Models Identified | Percentage Models Identified |
|---|---|---|---|
| Refrigerator | | | |
| Post 1977 | 603 | 295 | 48.9 |
| Pre 1978 | 1327 | 123 | 9.3 |
| Freezer | | | |
| Post 1977 | 109 | 51 | 46.8 |
| Pre 1978 | 263 | 17 | 6.5 |
| Room A/C | | | |
| Post 1977 | 13 | 1 | 7.7 |
| Pre 1978 | 60 | 1 | 1.6 |
| Central A/C/Heat Pump | | | |
| Post 1977 | 83 | 18 | 21.7 |
| Pre 1978 | 307 | 0 | 0 |
| Water Heater | | | |
| Post 1977 | 303 | 147 | 48.5 |
| Pre 1978 | 830 | 0 | 0 |
| Central Furnace | | | |
| Post 1977 | 163 | 72 | 44.2 |
| Pre 1978 | 921 | 1 | 0 |
| Wall/Floor Furnace | | | |
| Post 1977 | 18 | 6 | 33.3 |
| Pre 1978 | 185 | 1 | 0 |

Note: Table dated 5/9/84.

Table III. Summary of Marginal Average Efficiency Trends.

Summary of Marginal Average Efficiency Trends

| Vintage | Refrigerator (kWh/ft$^3$-month) | Freezer (kWh/ft$^3$-month) | Central[3] Furnace (Percent) | Water[4] Heater (Percent) |
|---|---|---|---|---|
| 1975-1977 | | | | |
| Worst | 10.64 | 12.94 | N/A | N/A |
| Average | 7.67 | 8.00 | N/A[1] | N/A[2] |
| Best | 4.61 | 3.95 | N/A | N/A |
| 1978-1980 | | | | |
| Worst | 10.79 | 10.94 | 61.1 | 76.0 |
| Average | 7.42 | 5.76 | 67.7 | 76.2 |
| Best | 4.46 | 3.46 | 76.5 | 78.0 |
| 1981-1983 | | | | |
| Worst | 7.44 | 8.62 | 55.7 | 76.0 |
| Average | 5.90 | 5.19 | 66.0 | 76.2 |
| Best | 3.42 | 3.88 | 76.7 | 78.0 |

1. Insufficient number of data points available for analysis. Industry estimate reported to DOE [2] was a 1975 AFUE percentage of 62.68 percent.

2. Insufficient number of data points available for analysis. CEC estimate of 1975 combustion efficiency is 72 percent.

3. Seasonal efficiency percentage.

4. Recovery efficiency percentage.

Note: Table dated 5/9/84.

Refrigerators show little change between 75/77* and 78/80 in either average or range of efficiency. 81/83 data show a dramatic improvement in average efficiency and a large reduction in the range of efficiency. Apparently, substantial shifts in average efficiency are caused mostly by elimination of the least efficient models, rather than by substantial increases in high efficiency offerings. Title 20 Appliance Standards imply a minimum efficiency ranging from 7.1-7.5, depending upon features such as automatic defrost and anti-sweat heater switches.

Freezers exhibit a different pattern. A substantial increase in marginal efficiency occurs between the 75/77 and 78/80 vintages, with only a little further increase for the 81/83 vintage. Title 20 implies a range of minimum efficiencies from 7.0-8.0, depending upon type and features.

Central gas furnaces show a slight decline in average efficiency between the 78/80 and 81/83 vintages. The 75/77 vintage does not yet have sufficient numbers of models identified to provide meaningful results. The CEC has a minimum seasonal efficiency standard of 71 percent that has had extended legal controversy regarding test procedures. Court mandates prohibited the CEC from enforcing this standard until December 1983. Competitive marketing pressures appear to have caused the introduction of less efficient models in the 81/83 vintage, compared to the 78/80 vintage.

Gas water heaters have similar model identification problems to gas central furnaces; insufficient 75/77 vintage models have been identified. No change in average or extreme efficiencies is noted between 78/80 and 81/83 vintages. The Title 20 standard requires a minimum recovery efficiency of 76 percent; this requirement appears to have been met by all units found in the survey. The average efficiency falls only slightly above the minimum required by the standard.

## Marginal Distrbution of Efficiency

The average efficiency statistics cited in Table III exhibit trends similar to those reported by industry/DOE [2]. The extremes reported in Table III have little to be compared to as the industry has been reluctant to share detailed sales statistics. Of great interest, of course, are the actual distributions of sales efficiency. A contribution of this paper is to make publically accessible some information about the distribution of the efficiency of appliance sales. Figures 1 through 4 report the marginal distribution of efficiency by vintage for each of the four appliance types.

Refrigerator efficiency distributions shown in Figure 1 parallel the results of Table III . Little change occurred between the 75/77 and 78/80 vintages, then a major shift to more efficient purchases occurred. Of particular note are the shapes of these curves; they are clearly not normal distributions. Each shows either flat or decreased proportions around the mean. The distributions appear increasing bimodal moving from 75/77 to 81/83. Refrigerator model characterization efforts have been vigorous and the numbers

*For simplicity of description, the following notation will be used: 75/77 refers to the 1975 to 1977 vintage. 78/80 refers to the 1978 to 1980 vintage, and 81/83 refers to the 1981-1983 vintage.

used to develop these curves sufficiently large that this is unlikely to be a misleading portrayal of actual events.

Freezer efficiency distributions shown in Figure 2 are less startling. Once again, the pattern of bimodal distributions shifting to more efficient models from 75/77 to 81/83 is apparent. The 75/77 vintage has a substantial number of models that were extremely inefficient. These have disappeared by the 78/80 vintage. 81/83 vintage efficiencies are narrowly clustered at two points, 4.00 and 6.00 kWh/$ft^3$-month.

Central furnace efficiency distributions shown in Figure 3 also present a confused picture. A dominant peak around 66 percent is obvious, along with other secondary peaks broadly scattered from the mean.

Water heater combustion efficiencies shown in Figure 4 have not changed between 78/80 and 81/83. A very large number of models have the minimum allowed by the standard--76 percent. Further work on model characterization will allow display of the 75/77 vintage which will provide some context for understanding these post-standard results.

Development of these distribution curves led to further analysis to uncover explanations for the underlying shapes and shifts across vintages. Work to date has focused upon product classes within appliance types.

## Product Class Variations

The physical attributes of refrigerators can be described in a variety of ways depending upon one's purpose. Industry is mainly interested in amenities of immediate interest to the consumer. Energy analysis tends to focus upon other aspects. DOE used eight product classes to cover the total refrigerator market in its "no standard" standards work. Current CEC standards recognize four types with sufficiently distinct characteristics that different levels of standard were required. For this analysis, the data available are those characteristics readily available in the CEC certification files or from decoding manufacturer model numbers. Four principal types were found in the data: top freezer, bottom freezer, side by side, and internal freezer. Of these, top freezer and side by side account for more than 95 percent of all models. Figures 5 and 6 compare the distribution of efficiencies for these two product classes for 75/77 and 81/83 vintages, respectively.

Figure 5, for the 75/77 vintage, exhibits profoundly different distributions for the two product classes. Side by side models are more efficient and have a much smaller range of efficiencies than do top freezers. One of the common myths of energy analysis is that side by side refrigerators are energy hogs. These data clearly dispell that notion. They do consume more energy, on average, but they are so much larger, about 4 cubic feet on average, that in a comparison of efficiencies, they may provide more service for the consumer. Top freezer models show a very broad distribution. Superposition of these distributions, with top freezers weighted approximately three to one, results in the combined refrigerator distribution for the 75/77 vintage in Figure 1. The bimodal shape's left peak comes from side to side models, and its right peak from top freezer models.

FIGURE 1

DISTRIBUTION OF REFRIGERATOR EFFICIENCIES BY VINTAGE

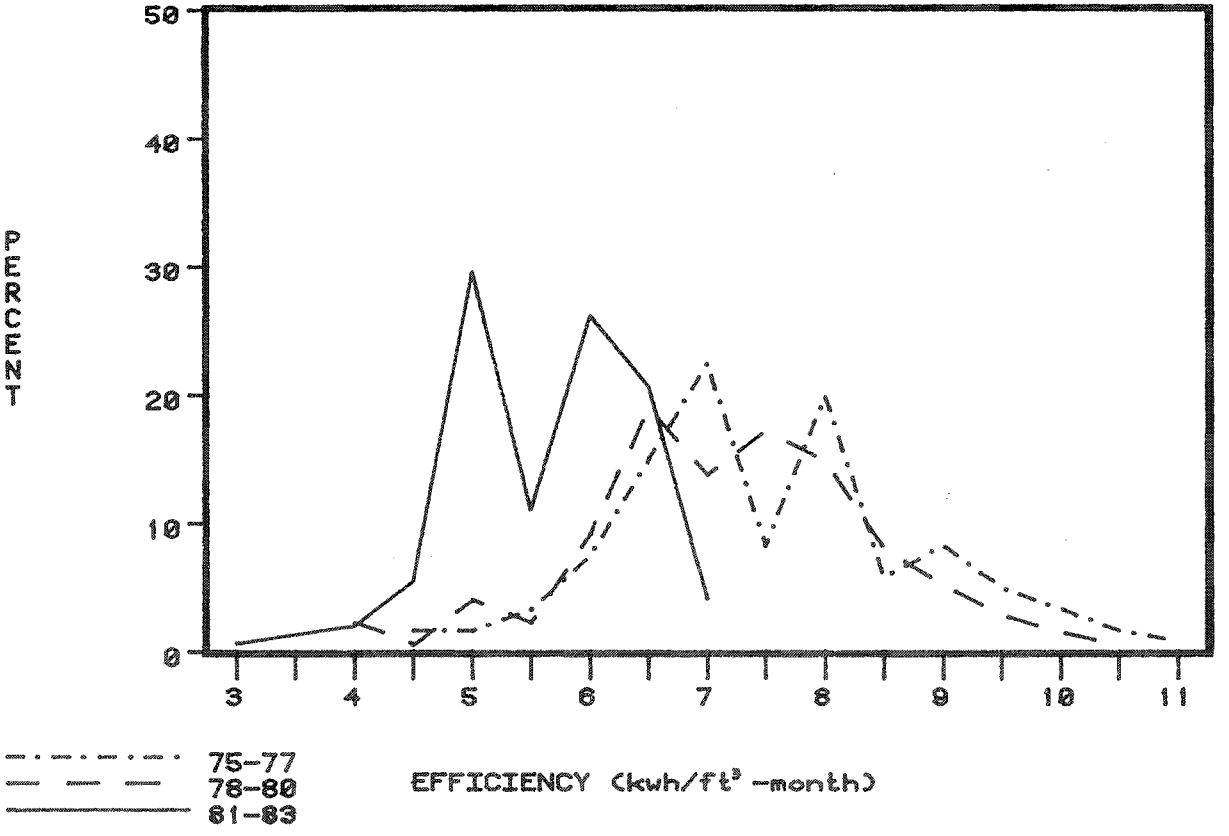


FIGURE 2

DISTRIBUTION OF FREEZER EFFICIENCIES BY VINTAGE

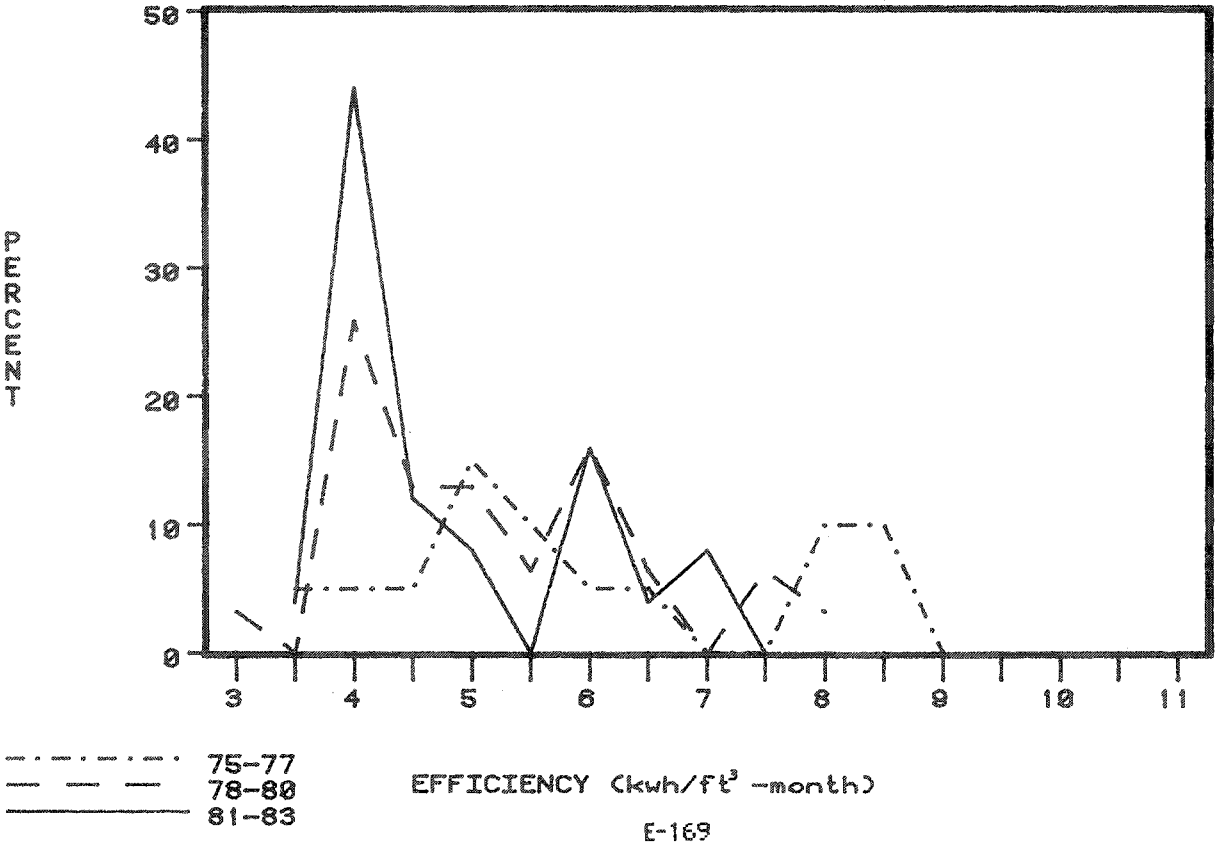

FIGURE 3

DISTRIBUTION OF CENTRAL FURNACE EFFICIENCIES BY VINTAGE

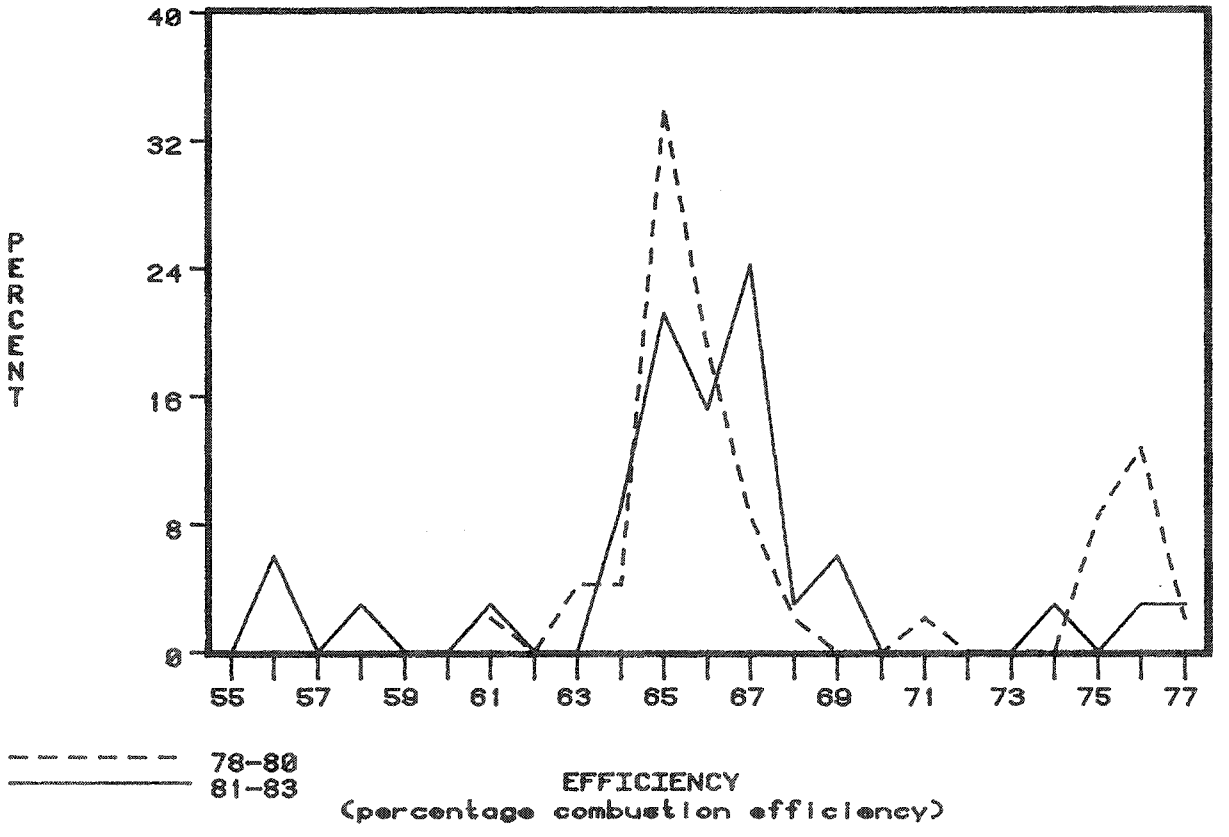


FIGURE 4

DISTRIBUTION OF WATER HEATER COMBUSTION EFFICIENCY BY VINTAGE

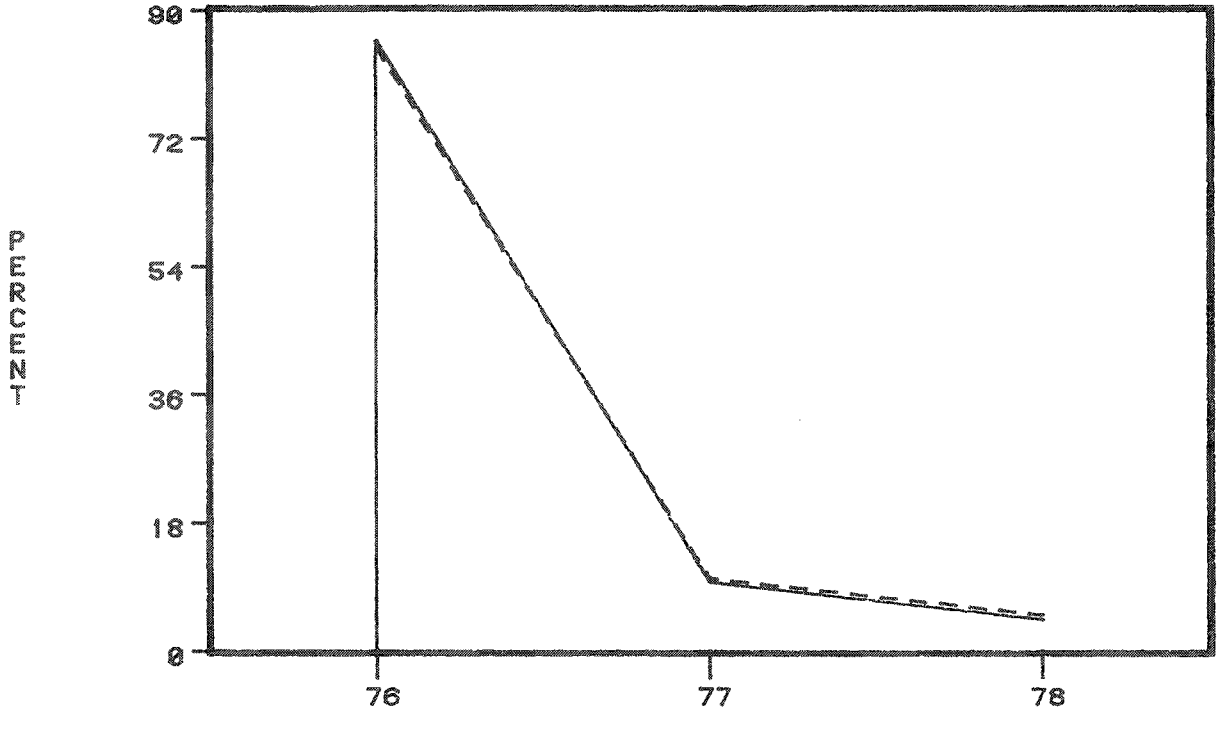

FIGURE 5

75-77 DISTRIBUTION OF EFFICIENCY BY REFRIGERATOR TYPE

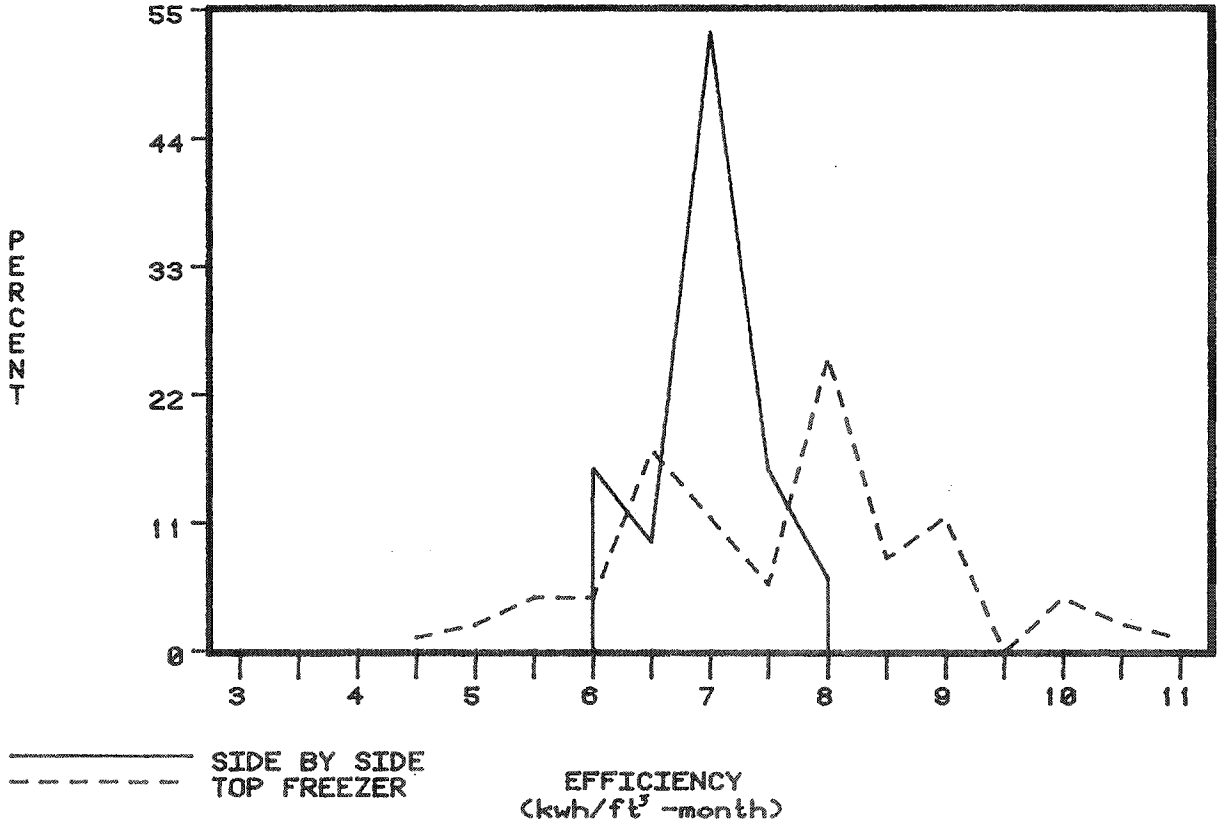


FIGURE 6

81-83 DISTRIBUTION OF EFFICIENCY BY REFRIGERATOR TYPE

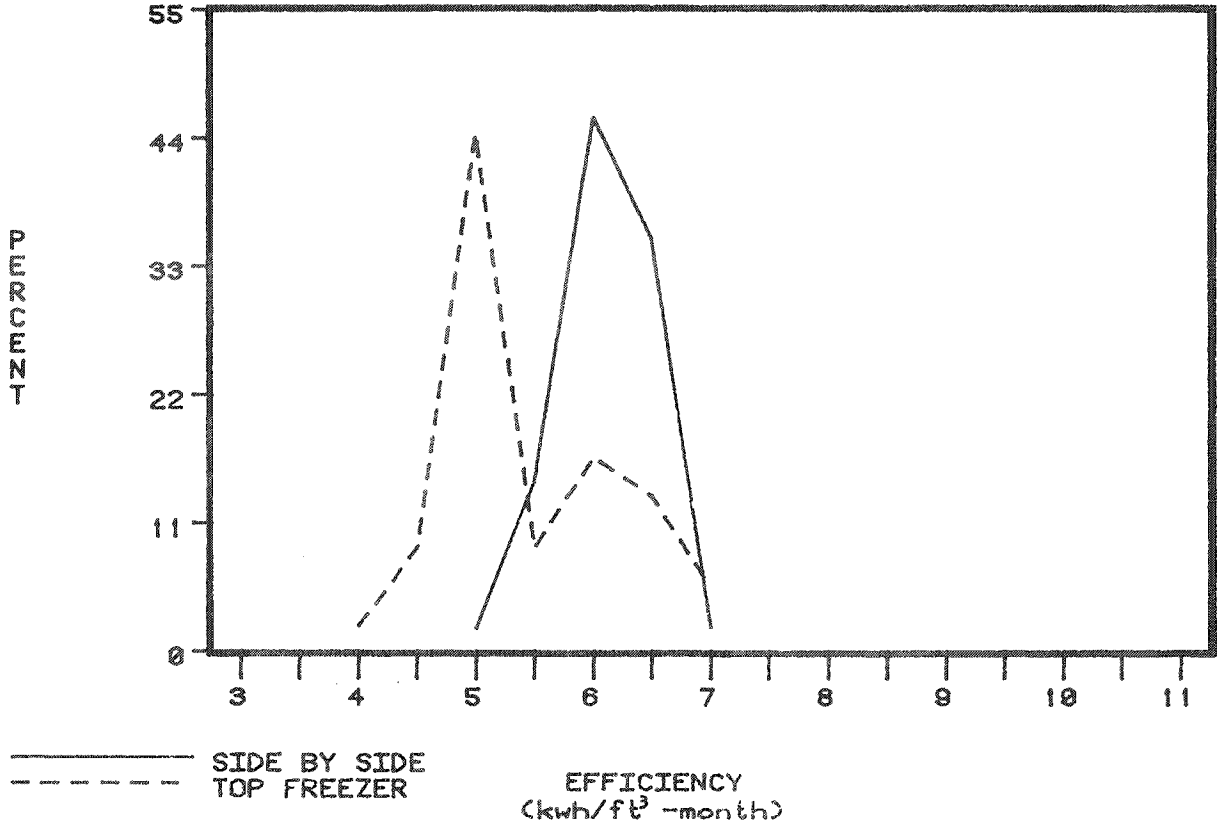

Figure 6 displays similar data from the 81/83 vintage. Several major changes seem to have occurred. Both product classes show distributions that are much tighter than in 75/77. Both exhibit compliance with the CEC standard of 7.0 kWh/ft$^3$-month. Top freezers, however, have become more efficient than side by side models. In fact, top freezers have improved dramatically from 75/77, while side by sides have improved only a little. As with the older vintage, the 81/83 distribution on Figure 1 can be approximated through an appropriate weighting of these two product class distributions.

This product class information seems to imply that aggregate appliance type data must be viewed with consideration caution. Appliance types with dissimilar product classes must be analyzed carefully to determine how each product class appears to be behaving. Shifts within appliance types among product classes may have important impacts on energy consumption.

## PRELIMINARY INTERPRETATION OF RESULTS

The results presented here are preliminary. Table II indicated how far the model identification process has come, much more remains to be done. However, some interpretation of the data can now be made with only low risk of error.

### Current Conservation Forces

Four forces are potentially at work today to improve the efficiency of appliances purchased in California--Title 20 Appliance Standards, response to high fuel prices, utility incentive and information programs, and manufacturer production decisions. For three of these appliance types --refrigerators, freezers and gas water heaters -- the Title 20 standards seem to be working; for gas central furnaces, legal prohibitions over standard enforcement have delayed removal of the most inefficient models.* The three other forces seem to be exerting some influence on high efficiency decisions for refrigerators and freezers; average efficiencies are substantially better than minimum requirements in each appliance. The shift in top freezer refrigerators efficiencies from 75/77 to 81/83 can only be interpreted as a wholesale redesign of product lines by the industry, although motivations for such changes are unclear. Central gas furnaces and gas water heaters do not exhibit much change even though PGandE gas prices rose 63 percent between 1977 and 1982.

### Program Implications

Upgraded or expanded conservation programs to achieve yet higher appliance efficiencies are currently under consideration in California for refrigerators, freezers and air conditioners. Standards undoubtedly remove inefficient models from the marketplace, but do nothing directly to encourage sales of high efficiency models. Tax incentives, utility rebate programs, and life cycle cost labeling are all options that could supplement this deficiency of standards. The first and last of these may not be viable in California

*Provisions in the test procedure for vent damper credits were disputed in administrative and legal forums. This dispute has now been resolved. New furnaces manufactured after December 1983 may be sold in California only if efficiency is greater than or equal to 71 percent seasonal efficiency.

given the current legislative climate. Utility rebate programs could be expanded but the cost effectiveness of such programs remains unknown at this time. In 1984, PGandE began a small scale pilot rebate program that may point toward larger efforts in the future. Current views about future fuel prices, now much less pessimistic than two years ago, may inhibit expanded efforts to achieve a larger portion of the conservation potential that high efficiency appliances offer to the consumer.

ACKNOWLEDGEMENTS

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