BUILDING APPLICATION OF SOLAR ENERGY

STUDY NO. 4:

SCENARIOS FOR THE UTILIZATION OF SOLAR ENERGY IN SOUTHERN CALIFORNIA BUILDINGS

5040-10 August 1975

Change 1, February 1976

Prepared for

The Southern California Edison Company

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BUILDING APPLICATION OF SOLAR ENERGY

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PREFACE

This report presents results from the fourth phase of a project to assess the use of solar energy for heating and cooling buildings which are served by the Southern California Edison Company (SCE). The overall goal of the project is to provide a basis for defining appropriate SCE objectives and R&D activities in this field.

The Project is organized into four separate but interrelated phases, each resulting in a separate study report. Study No. 1 describes 1) solar energy and weather statistics for Southern California and 2) region definition. Study No. 2 covers 1) building size definition, 2) building population projection, 3) selection of representative buildings, and 4) specification of HVAC energy requirements. Study No. 3 covers 1) case studies on selected buildings, 2) analysis of the operating characteristics of solar heating and cooling systems, and 3) an evaluation of solar heating technology of interest to an electric utility. Study No. 4 describes several possible market penetration scenarios for solar heating and cooling technology in Southern California.

The study team in the fourth phase of the Project consisted of E. S. (Ab) Davis, Task Manager, R. French, and A. S. Hirshberg. Alan Hirshberg was responsible for developing the input scenarios and the parametric equivalencies. R. French was responsible for integrating scenario, system performance parameters, system cost, and consumer adoption criteria into a model of the market. R. Bourke and J. Doane have been of great help to this phase of the Project. They have provided useful advice and comment on technical and management issues.

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SECTION I

INTRODUCTION

"In dealing with the future, it is more important to be imaginative and insightful than 100% right."

Alvin Toffler
Future Shock

The fundamental objective of this study is to outline plausible future market scenarios for solar heating and cooling systems into buildings in the area served by the Southern California Edison Company (SCE). This report provides a range of plausible estimates for the number of solar systems which might be installed and the electrical energy which might be displaced by energy from these systems. The effect on peak electrical load has not been explicitly calculated but preliminary conclusions concerning peak load can be inferred from the estimates presented. Two markets are investigated: the single family market and the large power commercial market.

Any attempt to project future market penetrations of an alternate energy product is fraught with difficulties. First, we are faced with many uncertainties: uncertainty as to the future cost relationship of the product and conventional energy; and uncertainty as to the availability of conventional energy. Second, the decision process that individuals employ in adopting new products such as solar heating and cooling systems is complex and difficult to quantify. Third, state and federal actions which might stimulate solar adoptions are also unknown. The complex and varied market for solar HVAC equipment is yet another problem facing any projection. The difficulty of projecting the market for solar heating and cooling systems is amply illustrated by the fact that NSF Phase O contractor projections (Refs. 1, 2, 3) of solar system market capture in the year 2000 vary by a factor of 30. The specific reasons for this apparent conflict are discussed in Appendix A.

One of the factors contributing to variability of the projections comes directly from the building industry. Historically, the building industry is relatively slow to accept new technologies and, according to Ref. 4, erects barriers to new methods and ideas. In addition, the National Association of Homebuilders

Research Foundation indicates (Ref. 5) that industry members often avoid the use even of cost-saving new technologies. The result is a 10 to 40 year spread in the time to reach widespread adoption of a new technology (Ref. 6).

The approach taken in this report is to bound the problem and to present the results in a manner that allows flexibility in interpretation. Three scenarios for future energy cost and availability provide a basis for estimating solar energy market penetration. These were chosen to provide estimates of the penetration of solar energy that would be high, medium, or low. Market penetration is triggered by investment decision criteria (which are treated parametrically) and market penetration rates are constrained by historical rates of adoption of other innovations by the building industry. The market penetration model considers a market which is disaggregated by microclimatic zone, type of competing conventional heating system, and fuel usage.

SECTION II

SUMMARY OF FINDINGS

A. LIMITATIONS OF THE DATA BASE AND THE MODELS

The plausibility of the scenarios for displacement of electrical energy by solar energy described in this report is limited by a number of factors. First, the market for heating and cooling of buildings is too complex to be completely described by any practicable data base; and the possible configurations of solar energy systems are too numerous to be treated comprehensively. Second, the models of consumer adoption criteria and market penetration have a weak theoretical and empirical foundation. However, the models have intuitive appeal and are based on the latest published research in the field of technology diffusion. Even so, the plausibility of the results of exercising these models depends on the validity of the postulated energy price scenario, postulated adoption criteria (e.g., required payback period, or equivalent return on investment (ROI), and level of "first cost" incentive), and postulated market share for conventional systems.

B. INSIGHTS INTO THE SINGLE FAMILY AND COMMERCIAL MARKETS

The market penetration of solar energy is very sensitive to postulated energy price and availability. If the availability of natural gas is curtailed and the pressure of increased electrical energy demand forces the price to rise faster than the inflation rate effect on the installed cost of solar equipment, then solar energy can have a significant role in heating and cooling in broad areas of the building market even if consumers require a 5-year payback period for adoption. Since builders of all new buildings are forced to chose between solar energy systems and all-electric systems, all solar systems become economic in an increasing number of applications as time goes on. Even with no incentives provided, and with nominal assumptions for cost and buyer decision criteria, market penetrations exceeding 10% are projected in both the single family and commercial markets. Because of the exponential growth in the price of electricity, first cost incentives advance the data of penetration to a specific fraction of the market. In the single family market a 25% incentive advances the date of 10% penetration by 7 years. A 50% incentive advances the date 7 years more, with the result that 10% penetration can be achieved by 1985.

If historical patterns of energy growth are resumed or if new patterns of decreased energy growth are sustained and consumers require a 5-year payback for adoption, then there is a more limited role for solar energy in the heating and cooling of buildings. Under Historical Growth and Retarded Energy Growth Scenarios, electricity rates are postulated to remain approximately constant relative to solar energy systems. Under conditions of constant relative cost only the most economic solar energy applications ever become adopted in significant quantities. In the single family dwelling market, solar energy space heating and water heating systems are potentially economically attractive. If the effective first cost is 50% less than the postulated nominal, then solar energy will achieve a market penetration of 10% by the year 2000. In the commercial market the solar hydronic heat pump can penetrate 10% of its narrow portion of the market by 1985, even without incentives, but the total energy displacement is small.

The market penetration of solar energy is sensitive to factors affecting individual decision to buy. Given the price of energy saved by using solar energy, three factors affect the decision to buy: the cost of the equipment, the payback period required by the buyer, and the level of first cost incentive provided by a third party. In this study a nominal effective first cost was established which assumed 1) an accurate estimate for the installed cost of conventional components, 2) an optimistic (i.e., low) estimate for the f.o.b. price of a solar collector, 3) a 5-1/2-year payback period for single family buyers, and 4) no first cost incentives. If the first three assumptions are correct, then an incentive is needed to induce significant broad-based market penetration in the single family heating and water heating and the commerical cooling markets in all scenarios except gas curtailment. The level of incentive must effectively reduce the first cost by 25 to 50% to be effective. If an 11-year payback period is acceptable, then solar energy can be expected to achieve significant penetration under all postulated scenarios for future energy prices.

First cost incentives produce strong penetration into the "new" market before stimulating penetration into the retrofit market. In fact, the minimum incentive level for retrofit may well exceed the level required to achieve maximum penetration in the new market.

The "new" market and the retrofit market are both important. By the year 2000, half of the in-place single family residences will have been constructed before 1975. A small penetration rate into the large existing building population can produce significant electric energy displacements.

Market penetration is similar in all microclimatic zones. The share of the energy market captured by solar energy systems is not very sensitive to microclimatic zones.

C. IMPLICATIONS FOR OTHER MARKETS AND OTHER SOLAR ENERGY SYSTEM DESIGNS

Any system that is economically attractive can penetrate to 10% of the market by 1985 and to over 40% by the year 2000. Therefore, systems which would be attractive if they were widely available could have a significant impact. Solar water heaters and solar hydronic heat pump systems for multiple family dwellings would have significant impact in all three energy price and availability scenarios postulated. Advanced systems for the single family dwelling which combine solar heating with off-peak cooling are suspected to be economically attractive and could be expected to penetrate the market.

D. IMPLICATIONS FOR FUTURE EDISON LOAD

The use of solar energy in buildings will have negligible impact on the growth of Edison peak load prior to 1990. Given the proper incentive, space heating and water heating are the principal solar functions which penetrate the residential market. Air conditioning does not appear competitive in the single family market unless it is combined with a space and water heating system. The solar cooling systems examined reduce electrical loads for cooling by 25% on peak days while displacing well over 50% of the annual electrical energy for cooling. The combined solar space heating, space cooling, and water heating systems could penetrate the commercial market if adequate first cost incentives are provided. However, the estimated level of energy displacement does not reach 10% until after 1990 except under the most extreme circumstances — very high energy prices and low availability (i.e., the Gas Curtailment Scenario).

The off-peak-power auxiliary cooling feature included in the commercial design was not explicitly studied. However, we suspect that this system might be economically viable and that it could be advantageously applied in all markets in conjunction with solar space heating. This could make solar space heating more economically attractive and reduce utility peak loads. If economic (and it is certainly closer to economic than solar cooling is) the off-peak-power cooling system could have a significant effect in reducing peak load growth by 1990.

If solar heating systems with electric auxiliary penetrate the all-electric market there is no effect on the Edison peak load, since it is a summer peaking utility. However, total kWh sales would be reduced. If on the other hand solar heating systems with electric auxiliary penetrate the natural gas heating sector of the market, the winter peak of the Edison Company would grow along with kWh sales. At least 200,000 such systems could be installed before the Edison Company would be converted to a winter peaking utility.

E. RECOMMENDATIONS FOR FURTHER RESEARCH

The analysis should be extended to areas not specifically included. The multiple family dwelling market should be examined explicitly, using the existing techniques. This market is more complex than either the single family or commercial market but several systems have been estimated to be potentially attractive to the market under current energy prices. The market penetration of advanced systems should be studied. Off-peak-power cooling-only systems, along with combined solar space heating and off-peak-power cooling system, should be studied in all markets.

The market penetration analysis should be carried out using the economics of the combined "Edison plus customer" interest group for the decision criteria.

The capability of the model should be extended to provide the capability to separately examine the displacement of fuel and peak capacity.

This analysis should be updated periodically. Most of the factors which affect the market penetration of solar energy are subject to change.

The scenarios for energy price and availability should be an area of continuing study. Even the gas curtailment scenario, which is a clear-cut limiting case, should be further developed with regard to specific allocation rules involved in the curtailment.

The Market Penetration Scenarios should be studied parametrically. The senstivity of market penetration to energy price growth rate and the growth rate of all-electric homes should be determined by more detailed parametric analysis than has been conducted. Parametric studies of the penetration rate should be conducted. The empirical data supporting Fisher-Pry diffusion time constants (i.e., penetration rates) could be wrong in the case of solar energy under current conditions of the energy market.

SECTION III

SOLAR HEATING AND COOLING SYSTEM MARKET MODEL

A. OVERVIEW OF THE MODEL

A model of the market for the solar heating and cooling system has been constructed which computes 1) the number of buildings which adopt solar energy systems and 2) the resulting reduction in total electrical energy consumed. This model calculates scenarios for the penetration of solar energy given 1) scenarios for future energy availability and cost, 2) a numerical description of the conventional heating and cooling system market, 3) a set of assumptions concerning which heating and cooling submarkets are in competition with solar energy systems, 4) parameters for the cost and performance of solar energy systems, 5) a set of assumptions related to buyer decision criteria (required payback period or ROI), 6) the level of "first cost" incentive that is available to the buyer, and 7) assumptions concerning the market penetration rates.

The model has been applied by making several underlying assumptions which are important to understanding the results. Homogeneous building population — the solar energy system cost and performance and energy consumption for a single building are used for all building in the population. Constant dollars and mass production prices — the 1974 installed cost of solar energy systems has been estimated assuming that markets adequate to achieve ultimate mass production prices exist. The inflation of energy prices, when studied, is tied to a constant-dollar index based on the estimated 1974 cost of solar energy components and 1974 construction costs. 1980 technology — solar collectors and heat-actuated chillers with the performance characteristics projected to be commercially available by 1980 are assumed. Consumer economics apply — the investment decisions are made by the consumer, who considers only those economic factors which affect him. Energy billing structures do not change — although the price of electricity and natural gas may change relative to solar energy, "demand charge" rate schedules continue to apply to the same classes of customer as in 1974.

B. ENERGY PRICE AND AVAILABILITY SCENARIOS

One of the most difficult problems in trying to assess the impact of solar energy in the next 25 years is the uncertainty regarding the price and supply of fossil fuels. In order to deal with this uncertainty, three scenarios are developed which bound the maximum and minimum penetration rates for solar energy: 1) the Gas Curtailment Scenario, 2) the Historical Growth Scenario, and 3) the Retarded Energy Growth Scenario.

The Gas Curtailment Scenario postulates a continuing reduction in the supply of natural gas so that by 1978 there is an embargo on all new natural gas hookups; existing firm customers at that time are postulated to continue to buy natural gas. The result is a switch in fuel use for new buildings to 100% electric (all-electric residential building comprise about 10-15% of the new market as of 1974). The price of electricity rises from the current \$0.035 per kWh* at a 4% annual rate above inflation (that is, a 4% growth rate in constant 1974 dollars); natural gas prices rise at the rate of inflation in this scenario. This scenario will produce the highest solar energy penetration, since solar energy competes best with electricity and this scenario postulates running out of natural gas for new hookups and a moderately high growth rate for the price of electricity.

The Historical Growth Scenario postulates a constant price of electricity at \$0.035 per kWh. The retail price of natural gas is postulated to double by 1978 and thereafter to increase at a 5% per year rate above inflation. With this growth in the price of natural gas, no embargoes on new hookups occur in this scenario, and continued growth in the use of electricty for building energy functions is postulated. Even so, the growth total demand for electrical energy may be moderated by energy conservation measures.

The third scenario, the Retarded Energy Growth Scenario, postulates a constant electricity price at \$0.035 per kWh (in 1974 dollars) until 1985, after which time the price declines in real terms slowly (-0.33% per year). After doubling at 1978, natural gas price remains constant (in real terms) through

*These prices are for residential customers. For commercial customers the A-7 rate structure resulted in an average value \$0.030 per kWh of energy displaced by the system studied.

2000 according to this scenario. This scenario postulates a trend away from electricity for building thermal applications.

These three scenarios bound the upper and lower limits vis-a-vis the cost competition between solar energy and conventional fuels. The Gas Curtailment Scenario produces the most attractive economic competition for solar energy; the Retarded Energy Scenario produces the least attractive economic environment for solar. The Historical Growth Scenario produces intermediate solar competitiveness. A detailed description of each scenario is given in the next section.

Each scenario has four components: one for energy price, one for energy use mix on existing buildings, one for energy use mix on new buildings, and one for energy conservation. The first three of these components are illustrated in Fig. 1. All energy scenarios assume that all buildings built after 1975 will be energy-conserving. The assumed energy-conserving packages are consistent with California energy legislation and ASHRAE recommendations (Ref. 7).

Furthermore, existing all-electric buildings are assumed to be energy-conserving. Existing residential buildings using gas for space heating are assumed to be retrofitted with 6 inches of fiberglass insulation in the ceiling while commercial structures will utilize nighttime thermostate set-backs to reduce energy use.

C. CONVENTIONAL HEATING AND COOLING SYSTEM MARKET DESCRIPTION AND ALLOWED SOLAR ENERGY COMPETITION

The basic conventional heating and cooling system market has been disaggregated by microclimatic zone and by end use function. The Beach Zone, the Inland Valley Zone, and the High Desert Zone are considered separately in the model. Within each of these zones the functions which can be served by solar energy are further disaggregated. In the single family market, the market is split between those buildings which have air conditioning and those that only have water heating and space heating. In the commercial market all buildings are assumed to have water and space heating as well as air conditioning. Within these functional splits the market is further disaggregated by 1) the fuel which supplies these functions, 2) whether or not the building is energy-conserving,

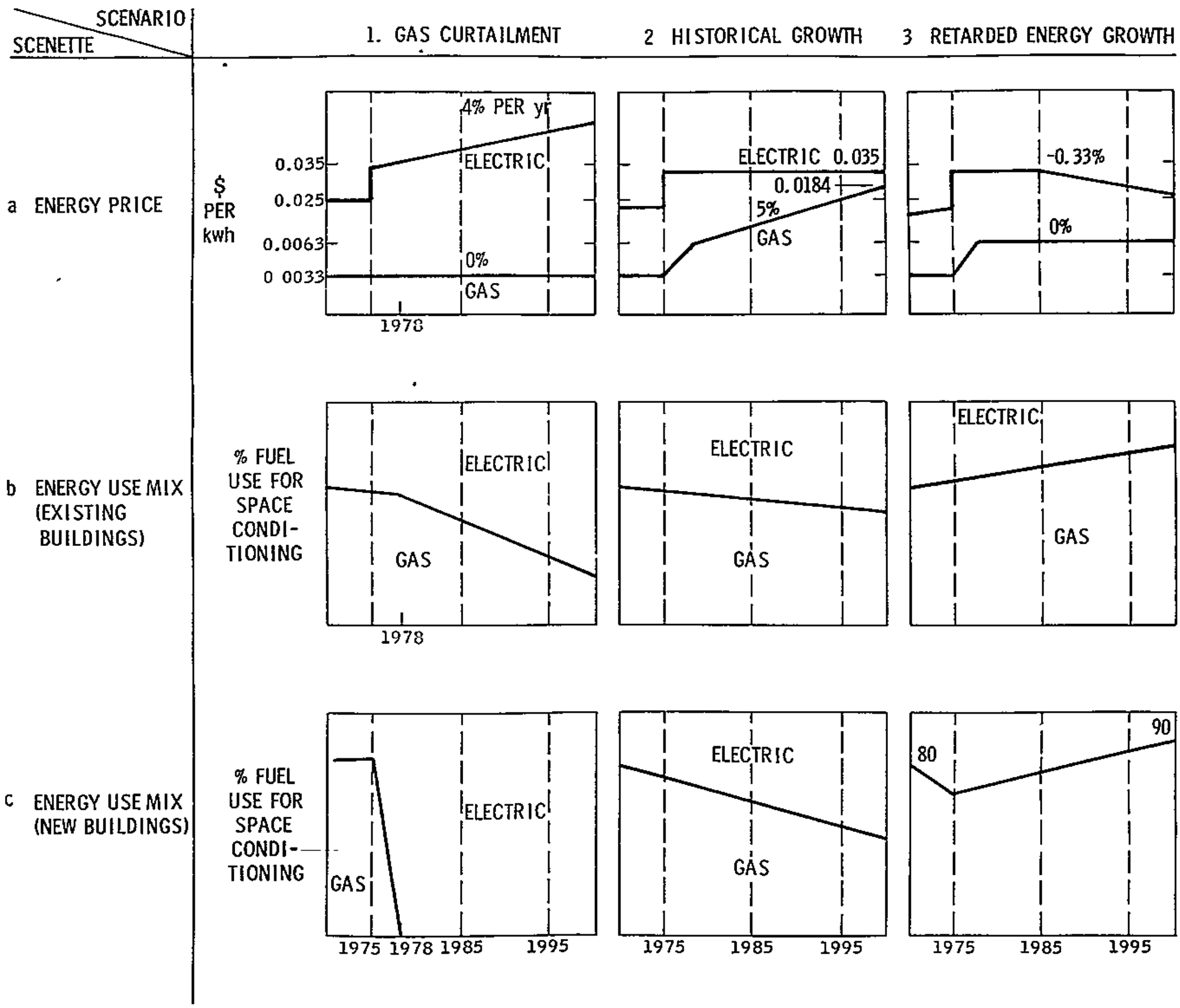

Fig. 1. Scenarios for Market Penetration.

3) and the type of conventional system (fan coil, heat pump, variable air volume) used.

The structure of the actual market is clearly complex. Data to describe the present and future market with the particular disaggregation which is appropriate for this study is not available. A simplified breakdown of the market has been synthesized based on Ref. 8. This breakdown is described in Appendix B.

In the single family market five solar energy systems are allowed to compete with conventional systems. The solar energy systems have 1) a solar water heating system, 2) a combined solar water and space heating system, 3) a solar space heating only system, 4) a combined solar water heating, space heating, and cooling system, and 5) a solar-augmented heat pump. These systems are all described in Ref. 9, Chapter IV.

In the commercial market three systems are allowed to compete with conventional systems. The solar systems are 1) a solar cooling system, 2) a combined system supplying heating, cooling, and domestic hot water, and 3) a solar-augmented hydronic heat pump. These systems are described in Ref. 9, Chapter VI.

In total 34 separate competitions are considered in both of the markets considered. The cost and energy displacement parameters of each of these potential adoptions of solar energy are tabulated in Appendix B in each of the disaggregated markets described above.

The following assumptions were made about the operation of the market:

1) No building may receive more than one solar energy system during the period under study.

2) Only buildings with a life expectancy of 25 years or more are candidates for solar energy system modifications, i.e., all building demolition occurred in that population segment which had not adopted a solar system modification.

3) The office building death rate is zero.

4) Natural gas never replaces electricity and electricity never replaces gas in any existing building HVAC* function.

5) All new buildings are energy-conserving by design.

6) The fractional mix of conventional HVAC systems in new buildings is a variable controlled by input data, i.e., conventional systems do not compete with each other for shares of the market.

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*Heating, ventilating, air conditioning.

D. POSTULATED ADOPTION MECHANISM

1. Commodity Substitution Framework

The adoption of a solar energy system is postulated to be a commodity substitution decision. Solar energy systems will be used to save energy. Thus the decision is one of choosing between conventional fossil fuel or electricity on the one hand and solar energy on the other. The least expensive option is chosen.

The rational approach to a commodity substitution decision is for the decision maker to perform an investment analysis. Several factors are involved in this analysis: equipment costs, savings, and financing on the cost side of the analysis. Solar energy equipment has a higher first cost, but incentives might be provided to reduce this first cost. On the savings side of the investment analysis, the amount of conventional energy which must be purchased each year is reduced. Financing makes it possible to put first cost and annual savings on a comparable basis. However, financing also involves risk and individual preference concerning the acceptance rate of return on investment (ROI).

The adoption mechanism is a nonlinear process involving factors which are uncertain. Put mathematically:

if: the $AS \geq (1 - I) \times (FC) \times (CRF)$ (1)

then: adopt the solar energy equipment

otherwise: stay with the conventional system

where: AS = The Annual Savings

I = The level of first cost Incentive

FC = The First Cost of the solar energy system installed (collector cost + non-collector cost)

CRF = The Capital Recovery Factor corresponding to the required ROI and the expected life of the system, n

$$= (ROI) \frac{(1 + (ROI))^n}{(1 + ROI)^n - 1}$$

$$= \frac{1}{\text{payback period}} .$$

To compute the annual savings, AS, and therefore to determine whether or not solar energy equipment will be adopted, one must know all four factors: I, FC, ROI, and n. Unfortunately, there is a great deal of uncertainty as to the values that should be used for any of them.

2. Postulated Minimum Acceptable Rate of Return on Investment

Decision makers in each submarket are postulated to have different levels of risk aversion. Therefore the minimum acceptable rate of return is postulated to be different for different building industry submarkets reflecting the relative conservatism of respective submarkets. In the commercial submarket a nominal rate of return equal to the cost of money (8 - 12%) is postulated to be required to stimulate adoption. In the single family submarket, however, a rate of return equal to 18 - 20% is postulated to reflect the higher "first cost" sensitivity of the single family submarket. These assumptions are identical to requiring a 5- to 5-1/2-year payback period in the single family submarket and an 8 - 10-year payback period in the commercial market.* The nominal values used for this study are presented in Table 1 for the new and retrofit markets.

Table 1. Required ROI for Solar System Market Penetration.

Submarket	New		Retrofit	
	Decision Maker	ROI-%	Decision Maker	ROI-%
Single Family	Builder	18	Owner	20
Commercial	Builder	8	Owner	12

*A survey of the adoption of new products in the building industry indicates that payback periods of 5 - 7 years are often required by potential new users.

It is possible that payback periods as long as 10 to 11 years may be adequate to stimulate adoption in the single family submarket. It is also possible that shorter payback periods may be required in the commercial submarket.

3. First Cost of Solar Energy Systems

The nominal market penetration analysis assumes a solar collector cost of \$2.77* f.o.b. the factory. This is estimated to be the mass production price for a double-glazed flat plate collector with a selective coating but no metal parts. Installation on the roof of a building is estimated to bring the installed cost to \$5.11 per ft^2. (This does not include the costs associated with non-collector components such as storage tanks and manifold plumbing.) If the collector target cost is not eventually met the installed cost could be double the \$5.11/ft^2 estimate. In prototype installation being constructed in 1974 and 1975 array costs have exceeded \$20 per ft^2.

4. "First Cost" Incentives

The possibility of government incentives which reduce the effective first cost of solar energy systems must be considered. The incentives could take a variety of forms — low interest loans, tax credits, accelerated depreciation allowances, tax exemptions. Each type of incentive can be interpreted as a reduction in the initial-cost of the solar system. From our analysis of proposed and pending legistlation at the federal level, some form of incentive appears to be likely. (For example, H.R. 6860 which provides a 25% incentive to residential users of solar energy has passed the House and is in conference.) Three different incentive levels are considered to be possible: 1) no incentive, 2) 25% incentive, and 3) a 50% incentive.

5. The Annual Savings

Although the annual energy savings can be calculated with reasonable good accuracy the value of this savings is somewhat uncertain. The uncertainty stems from the expected future price of conventional energy. In computing the annual savings the market penetration model postulates that the decision maker expects the price of the energy to remain constant over the life of the system.

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*1974 constant dollars.

6. Adoption Parameter Equivalence Groups

The uncertainty of the adoption mechanism suggests the need for a parametric study. The parametric study has been simplified by recognizing that the three parameters influencing adoption can be grouped in ways which produce the same market penetration results. Referring to the adoption inequality discussed in Para. 1, the product (1 - I) × (FC) × (CRF) is simply the annual cost of the solar energy equipment. The same specific annual cost will occur using many different combinations of the three parameters: incentive level, first cost, capital recovery factor. The level of market penetration only depends on the specific annual cost, and not on specific combination of parameters. Equivalent combinations of these three parameters are presented in Table 2 for three levels of the annual cost used in the analysis of the single family dwelling submarket: 100% of the nominal annual cost, 75% of the nominal annual cost, and 50% of the nominal annual cost. The nominal annual cost is the cost assuming a 5-1/2-year payback period, an installed collector cost of \$5.11 per ft^2, and no first cost incentive.

Table 2 is used as follows: From b) in Table 2 one concludes that identical annual savings are realized for any of the combinations

Collector cost = \$ 5.11/ft^2, Incentive = 0%, Payback = 7 yr

or

Collector cost = \$10.05/ft^2, Incentive = 25%, Payback = 7 yr

or

Collector cost = \$20.02/ft^2, Incentive = 25%, Payback = 11 yr

etc.

E. POSTULATED MARKET PENETRATION RATES

If all decision makers in each submarket were economically "rational," then once a new technology surpassed the decision criterion, it would be instantly adopted by all the members of the submarket. We know, however, that commodity substitutions and new technologies have never been adopted by everyone at once. Mansfield (Ref. 10) and Schon (Ref. 11) have shown that the adoption of new technologies by industrial firms varies from industry to industry. Fisher and Pry (Ref. 12) have investigated the substitution of new commodities and found that the time from 10% to 90% adoption ranges from 5 years

Table 2. Adoption Parameter Equivalence Groups.

a) For Annual Cost = 100% of Nominal.

		Incentive		
		0%	25%	50%
		Payback Period, yrs.		
Installed Collector Cost	$\$5.11/ft^2$	5-1/2		
	10.05	7		
	20.02	11		

b) For Annual Cost = 75% of Nominal.

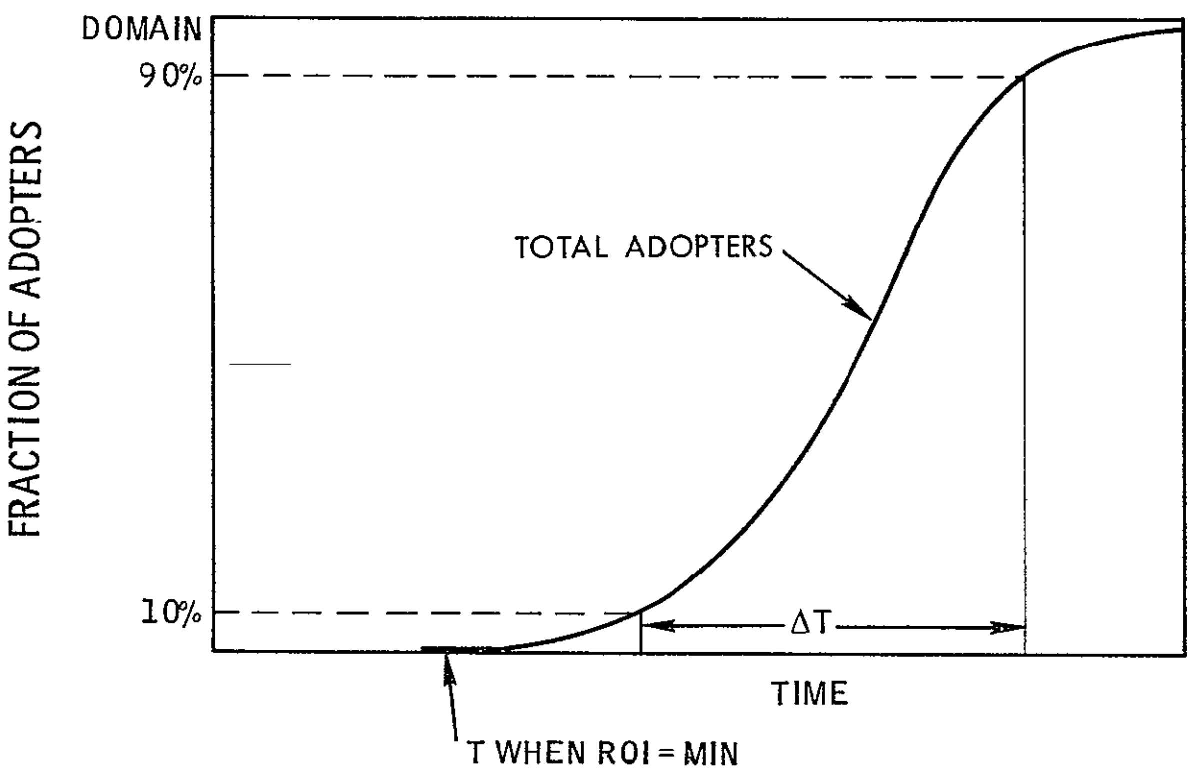
		Incentive		
		0%	25%	50%
		Payback Period, yrs.		
Installed Collector Cost	$\$5.11/ft^2$	7	5-1/2	
	10.05	11	7	
	20.02		11	

c) For Annual Cost = 50% of Nominal.

		Incentive		
		0%	25%	50%
		Payback Period, yrs.		
Installed Collector Cost	$\$5.11/ft^2$	11	7	5-1/2
	10.05		11	7
	20.02			11

(substitution of detergent for soap) to 58 years (substitution of synthetic rubber for natural rubber).

The reasons for these lags in the adoption (or substitution) of new technologies is the subject of diffusion research. Indications are that this process is affected by the exchange on information in such a way that the new item is adopted as the information concerning its benefits becomes known to potential adopters (Ref. 13). Researchers have found that the adoption process tends to follow the form of an S-shaped curve over time, with the rate of new adopters starting slowly, increasing to a maximum, and then declining again. The form of the rate curve over time has been found to be nearly normal (Ref. 14). Figure 2 shows the form of the total adoption curve as a function of time.



ΔT = Takeover Period for New Innovations in Building Industry.

Fig. 2. Historical Innovation Diffusion Curves.

To simplify the analysis, straight line approximations to the S-shaped curves were selected for use in this study.* These were chosen as representative of the takeover periods for new innovations in the building industry, which range from 10 to 30 years (Ref. 6). For a takeover period of 10 years, the approximate straight line annual penetration rate is 5%. Table 3 summarizes the approximate rates for three takeover periods used in this study.

Table 3. Annual Penetration Rates for Straight Line Approximation to the Fisher-Pry Growth Curve.

Δt (years)	Annual Penetration Rate
10	5.0%
20	2.9%
30	1.3%

In this study, the straight line annual penetration rate determines the number of buildings that are modified each year. For retrofit, the candidate building population is dynamic. The population grows by the addition of new buildings, which were not built with solar equipment installed, and shrinks by the destruction of old buildings and prior retrofits. Therefore, the actual number of buildings modified each year may either increase or decrease depending upon the instantaneous population of candidate buildings.

In the real world, the process of new product market penetration is very complex. To a degree, the commodity substitution decision process together with selectable penetration rates provides some capability to reflect many of the real conditions.

In practice, it is reasonable to expect that penetration rates will be a function of ROI. If the ROI is much larger than some minimum required value,

*The error introduced by this simplification is comparable to the uncertainty in the underlying diffusion theory.

the decision to adopt a solar HVAC system will be more readily made and penetration rates will grow. To account for increased penetration with high ROIs, the penetration rates are assumed to increase discontinuously when the ROI exceeds a second critical level as shown in Table 4.

Market capture is also postulated to be a function of the total number of buildings which are capturable. The capturability of a building for a solar energy system is affected by 1) the expected life of the building, 2) the orientation of the building and possible restrictions of solar collectors, 3) setbacks and shadows from neighboring buildings, 4) the adaptability of solar to the existing conventional HVAC system, etc. Westinghouse estimates that only about 65% (Ref. 2) of existing family units are suitable for solar system retrofits. Because more flexibility is afforded new buildings, a higher capture level of 75% has been assumed for the adaptability in the new market.

In summary, the decision to buy solar energy systems is assumed to be made using an ROI which is appropriate for the key decision maker in each of the building industry submarkets. This ROI is determined by estimating the ROI required for a commodity substitution. No penetration is assumed to occur until solar systems produce at least this required ROI criterion. Once the ROI criterion is met, the penetration is assumed to follow a straight line approximation of the Fisher-Pry diffusion curve. The penetration rates are based upon historical penetration rates of new technologies in the building industry. In the retrofit market, the penetration rate is assumed to increase to a higher rate when (and if) the solar system ROIs reach a second higher level. The overall penetration starts at zero in the year the ROIs first reach the minimum criterion and grows at a constant rate until 100% of the possible adoptions occur.

Table 4. Market Penetration Rate Assumptions.

Submarket	Decision Maker	Max. Penetration Fraction	New		Retrofit	
			ROI Range,%	Penetration Rate, fraction/yr	ROI Range,%	Penetration Rate, fraction/yr
Single Family	Homeowner	0.65	—	—	ROI < 20	0.0
			—	—	20 < ROI < 25	0.013
			—	—	25 < ROI	0.025
	Builder	0.75	ROI < 18	0.0	—	—
			18 < ROI	0.029	—	—
Commercial	Owner	0.65	—	—	ROI < 12	0.0
					12 < ROI < 15	0.013
					15 < ROI	0.025
	Builder	0.75	ROI < 8	0.0	—	—
			8 < ROI	0.029	—	—

SECTION IV

SOLAR ENERGY PENETRATION SCENARIOS FOR THE SINGLE FAMILY MARKET

A. INTRODUCTION

Nine plausible market penetration scenarios are developed for the single family dwelling market. Each scenario is an aggregation of three separate scenarios calculated for both the "new" and retrofit market in the Beach, Inland Valley, and High Desert Zones. Each of the nine scenarios involves a combination of 1) one of three energy price and availability scenarios and 2) one of three assumptions concerning the effective annual cost of solar energy to the buyer. The scenarios cover the period from 1975 to the year 2000.

Independent of solar energy use, the character of the single family building market is projected to change significantly by the year 2000. This is brought about by the assumptions that buildings constructed after 1975 will be significantly more energy-conserving than pre-1975 buildings. New buildings are postulated to be added at a 2.4% annual rate and old buildings removed at a 1% rate. By the year 2000, the building population will have increased from 1.64 million to 2.35 million but half of the 2.35 million buildings will be of post-1975 construction. If an energy-conserving building utilizes only half of the HVAC energy used by a standard building, then the rate of increase in the consumption of all forms of energy (gas, electricity, and solar) for thermal applications is approximately zero.

The growth in the number of post-1975 buildings is also significant, because solar energy systems are more competitive when installation is accomplished at the time of initial construction. In this study the cost of a new installation is assumed to be 20% less than the cost of a retrofit installation. Furthermore, the ROI required for adoption decision is assumed to be lower for new construction (18%) than for existing buildings (20%). New building construction is therefore postulated to be a more favorable market.

B. PENETRATION SCENARIOS

Table 5 presents nine scenarios for the future substitution of solar energy for the electrical energy that would otherwise be used for heating, cooling, and water heating by single family homes.

The Gas Curtailment Scenario produces the greatest penetration of solar energy systems and produces a 10% displacement of conventional energy sources by the year 2000 under nominal circumstances. If the effective solar energy cost is reduced by 25% (nominal less 25%), then the penetration of solar energy systems reaches 25% by the year 2000. The effective solar energy cost could be "nominal less 25%" if buyers will accept a 7-year payback, or will accept an equivalent arrangement in a 25% first cost inventive. (Other fully equivalent ways to effect the same market penetration are given in b) in Table 2.)

Similarly for the Gas Curtailment Scenario, if the effective solar energy cost is reduced by 50% (nominal less 50%) then the penetration of solar energy reaches 36% by the year 2000. The effective solar energy cost to the buyer could be "nominal less 50%" if buyers will accept an 11-year payback, or will accept an equivalent arrangement in which they require the nominal 5-1/2 year payback but receive a 50% first cost incentive. (Other fully equivalent ways to effect the same market penetration are given in Table 2.)

As can be seen from Table 5 no penetration occurs prior to the year 2000 under the other scenarios unless potential buyers will accept 11-year paybacks (or require 5-1/2-year payback but receive a 50% incentive). If this criterion is met then solar energy will achieve a 12% penetration in the Historical Growth Scenario and a 6% penetration in the Retarded Energy Growth Scenario by the year 2000.

C. MARKET DYNAMICS

1. Time to Reach Significant Levels of Penetration

The dynamics of the market are most clearly illustrated by the Gas Curtailment Scenario. Three estimates for electrical energy displacement by solar in the Gas Curtailment Scenario are plotted in Fig. 3. The top dashed curve in Fig. 3 is the estimated electric consumption if solar penetration is zero. The increase over the years is a reflection of the Gas Curtailment Scenario, which forces the electric heating and cooling market share to

Table 5. Scenarios for the Penetration of Solar Energy into the Electric Energy Market — Electrical Energy Displacement.

- Single Family Dwelling Submarket

		Effective Cost of Solar Energy to Buyer		
		Nominal	Nominal Less 25%	Nominal Less 50%
Gas Curtailment Scenario	YEAR 1980	0.0*	0.0	3.3
	1985	0.0	2.1	11.2
	1990	0.7	7.0	20.8
	1995	3.7	15.7	29.4
	2000	10.2	25.2	36.1
Historical Growth Scenario	YEAR 1980	0.0	0.0	0.5
	1985	0.0	0.0	1.9
	1990	0.0	0.0	4.4
	1995	0.0	0.0	7.8
	2000	0.0	0.0	12.1
Retarded Energy Growth Scenario	YEAR 1980	0.0	0.0	0.4
	1985	0.0	0.0	1.3
	1990	0.0	0.0	2.6
	1995	0.0	0.0	4.0
	2000	0.0	0.0	5.5

*Percentage electrical energy displaced by solar energy for thermal applications.

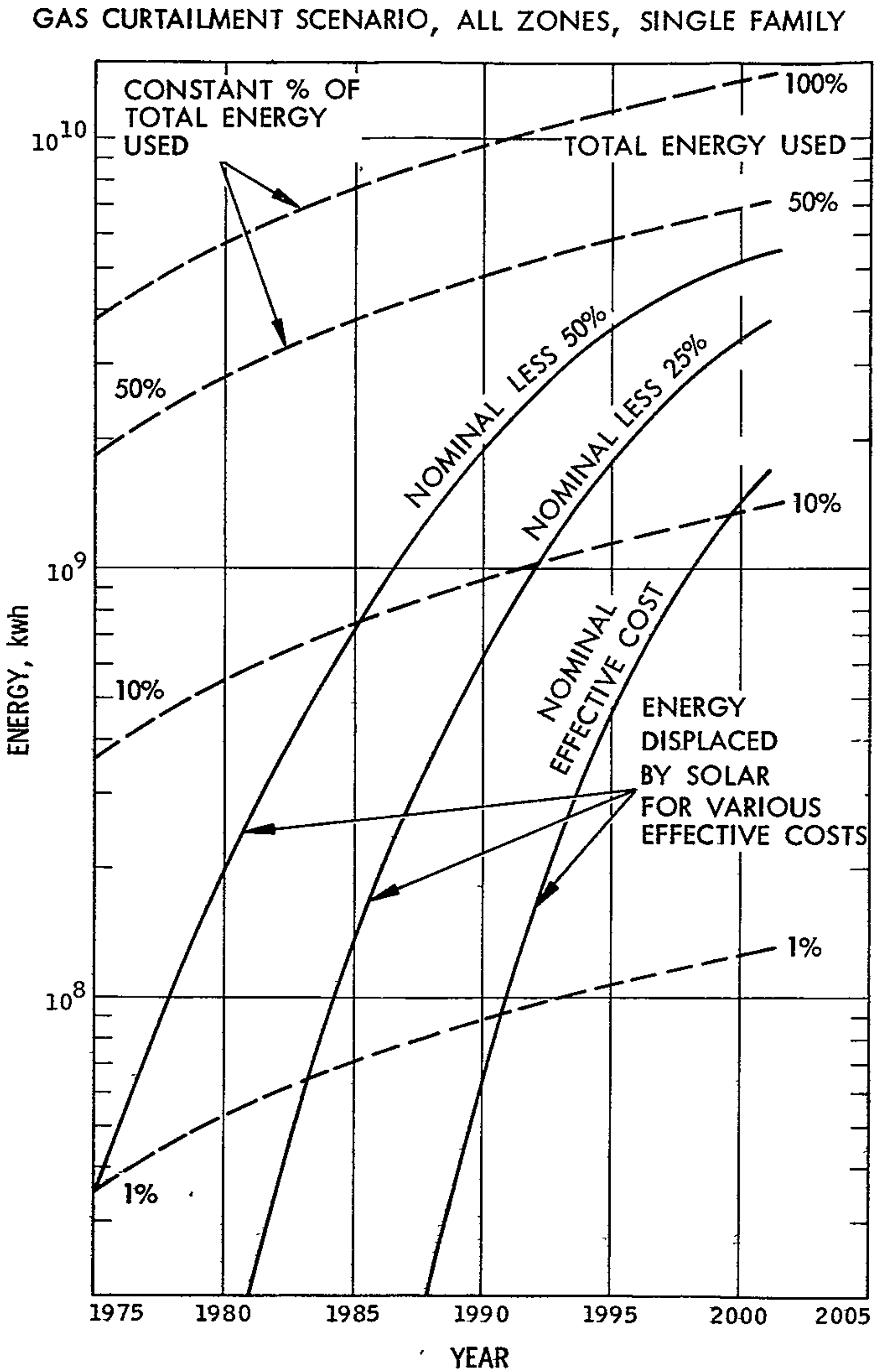


Fig. 3. Total Electrical Energy Displaced by Solar Energy.

dramatically increase since new gas hookups are restricted. The lower three solid curves reflect displacement of electrical energy by solar systems for three levels of effective cost to the buyer. The dashed curves are 10% and 1% reflections of the no-solar-energy-penetration curve and provide a visual aid for assessing the time when significant penetration is achieved. For example, 10% energy displacement is achieved in the single family residence market by 1985 if the effective first cost is nominal less 50%. If the nominal values for effective first cost prevail then 10% energy displacement is not reached until the year 2000.

The three curves in Fig. 3 can be interpreted as incentives of 0%, 25%, and 50% of the nominal first cost. The lower curve in Fig. 3 is the growth of energy displaced by solar energy, assuming no government incentive and a 5-1/2-year payback requirement before potential users buy solar systems. The second curve shows the energy displaced by solar energy if a 25% incentive is given. The third curve presents the energy displaced with a 50% incentive. With this interpretation of the curves the effect of a 25% incentive is to accelerate the time of 10% solar energy penetration from the year 2000 to the year 1992. A 50% incentive advances the 10% penetration milestone to 1985.

2. New and Retrofit Markets

The number of buildings in the "new" and retrofit markets modified by the year 2000 is shown in Table 6 for three incentive levels and the three scenarios. Strong penetrations in both the new and retrofit markets occur under the Gas Curtailment Scenario. The retrofit market is active because of the relative high cost of electricity and shows the importance of even small penetration rates into a large population. Many of the buildings in Table 6, which are eventually retrofitted with solar energy, are constructed after the time when solar energy is economically attractive in new construction. This is caused by the postulated process of market diffusion for solar energy systems. The other scenarios have lower solar energy penetration. No penetration into the retrofit market is produced under the Retarded Energy Growth Scenario. The lower penetration of solar energy in the Retarded Energy Growth Scenario compared to the Historical Growth Case is a consequence of the postulated shift away from the use of electric energy for space heating and water heating in new homes.

Table 6. Single Family Building Modifications by the Year 2000.

Scenario	Building Numbers			
	Incentive Level-%	Retrofit Modifications	New Modification	Total Modifications
Gas Curtailment	0	97,000	116,000	213,000
	25	300,000	285,000	585,000
	50	487,000	445,000	932,000
Historical Growth	0	0	0	0
	25	0	0	0
	50	0	138,500	138,500
Retarded Energy Growth	0	0	0	0
	25	0	0	0
	50	0	47,000	47,000

NOTE: This table only includes penetrations into buildings with electric heating and water heating.

3. Market Split by System

Six possible solar modifications have been designed for the single family residence. These solar systems are described in Ref. 8 and perform the following functions:

1) Water heating
2) Space heating
3) Water heating and space heating
4) Air conditioning
5) Water heating, space heating, and air conditioning
6) Heat pump heating.

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System 6 is limited in application to those buildings which would ordinarily choose or have chosen heat pumps. The remaining five systems compete with conventional systems and, in new building construction, with one another. In the new building market, solar system adoption is biased toward the system which performs the most HVAC functions. From the design numbers of Ref. 9, the relative economic competitiveness of the first five systems listed above is:

1) Water heating plus space heating
2) Space heating
3) Water heating
4) Water heating, space heating plus air conditioning
5) Air conditioning.

Thus, in new homes, only two systems penetrated the market: water heating plus space heating; and water heating, space heating plus air conditioning. In the retrofit market, all systems are candidates and many penetrate simultaneously once the critical ROI has been exceeded.

The relative penetration of the five competing solar HVAC systems is illustrated in Fig. 4. This figure shows number of buildings modified as a function of time for the Gas Curtailment Scenario and a 50% incentive. Curve "a" depicts the number of buildings that have adopted a solar water and space heating system. Curve "b" includes both the buildings of Curve "a" and those buildings with a solar space heating only system. Curve "c" adds to Curve "b" with water heating systems and finally Curve "d" is the total number of buildings modified. The solar-assisted heat pump and solar-air-conditioning-only systems are absent from Fig. 4. The solar-air-conditioning-only system did not achieve the critical level of ROI needed to initiate market penetration.

4. Comparison Between Microclimatic Zones

The market penetration of solar energy systems in each microclimatic zone for single family buildings was performed to determine differences between zones. The resulting energy displaced in the year 2000 in the Gas Curtailment Scenario is given in Table 7. The results show that solar energy will achieve the highest penetration in the Beach Zone with the High Desert Zone a close second. These results may seem counter-intuitive because the beach area often has fog and cloud cover particularly in the morning. Several factors

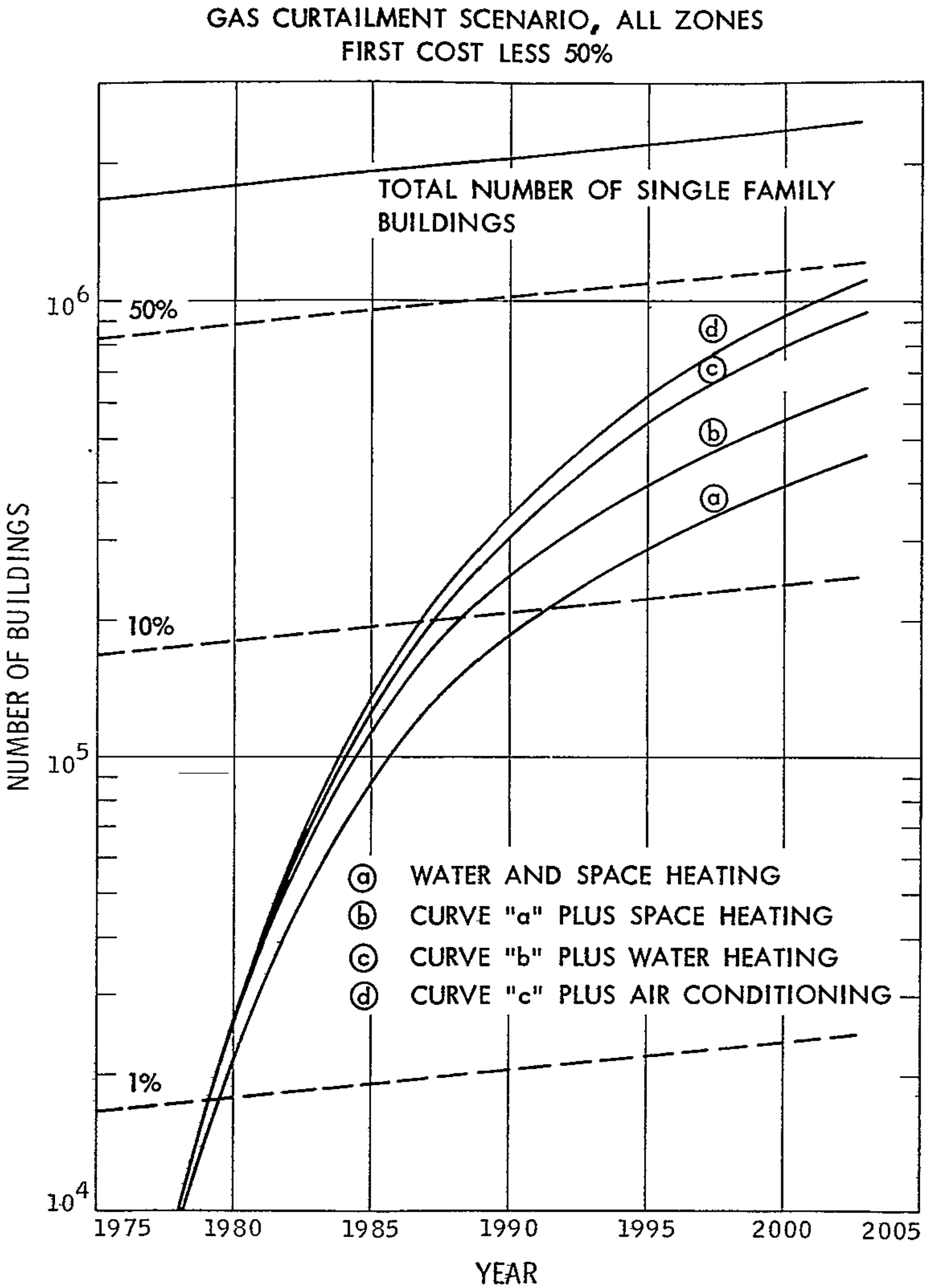

Fig. 4. Growth of New and Existing Single Family Buildings with Solar Energy Systems.

Table 7. Zone Comparison of Electrical Energy Displacement for the Single Family Residence.

• Gas Curtailment Scenario, Year 2000 (percent penetration)

	No Incentive	25% Incentive	50% Incentive
Beach 2430×10^6 Kwh	14	32	44
Inland Valley 8400×10^6 Kwh	8	23	34
High Desert 2140×10^6 Kwh	13	24	30
All Zones 13880×10^6 Kwh	10	25	36

cause this result. First, the milder climate at the beach causes solar space heating equipment to have higher utilization factor, making the economics of solar heating slightly better at the beach. In addition space heating is a larger share of the total HVAC energy budget at the beach. Since solar air conditioning does not penetrate the Inland Valley and High Desert markets until after 1990, the percentage of total HVAC energy displaced by solar is less.

SECTION V

SOLAR ENERGY PENETRATION SCENARIOS FOR THE COMMERCIAL MARKET

A. INTRODUCTION

Solar energy system performance and cost data for a 50,000 ft^2 office building is used to estimate the market penetration of solar energy in the commercial market. This building is in the large power rate class and is therefore on a demand charge rate schedule (A-7). The A-7 rate schedule was used to determine the average value of energy displaced by the specified solar energy system. Customers in the large power rate class use more total electrical energy than any other commercial/industrial class. Therefore the office building is reasonably representative of the bulk of the commercial market.

Although the number of office buildings is low compared to single family dwellings, the electrical energy consumption and potential solar energy use is high. Under the Gas Curtailment Scenario the required electrical energy for HVAC functions in the total large office building population is estimated to be 1.7×10^9 kWh/yr in 1980 increasing to 3.0×10^9 kWh/yr by the year 2000.

B. PENETRATION SCENARIOS

The amount of electric energy that can be displaced by solar HVAC systems can be significant, as is shown in Fig. 5. Figure 5 presents composite results for the Gas Curtailment Scenario. The top curve depicts the amount of electrical energy which will be required if no solar devices penetrate the market. The three solid curves below reflect the amount of electrical energy displaced for the Gas Curtailment Scenario in office buildings for three levels of annual cost. By the year 2000, the "nominal less 50% of first cost" case will cause solar penetration to displace 21% of the electrical energy demand; the "nominal less 25%" will displace 14%; and the nominal cost (the bottom curve), 11%. The "nominal less 50%" curve achieves a 10% energy displacement by the year 1993.

The lower penetration in office buildings compared to single family buildings is due to the relatively larger cooling requirement for offices.

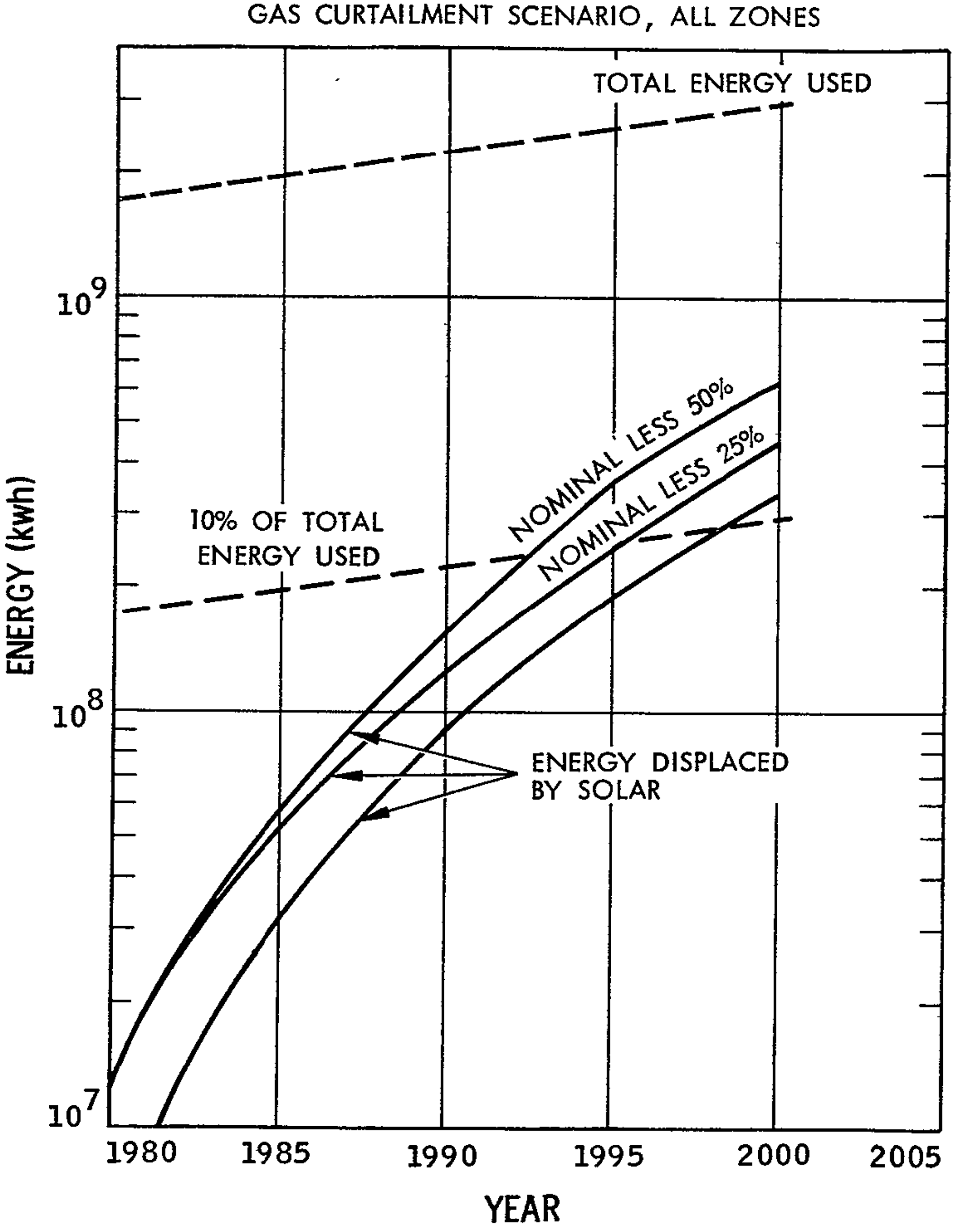

Fig. 5. Energy Displaced by Solar Energy Systems in Office Buildings.

Because near term technology for solar cooling is not expected to be as economical as heating, the percent penetration in office buildings is expected to be lower even though the nominal adoption criteria are less severe.

Table 8 summarizes the penetration of solar systems into the commercial market for all three scenarios. The percent of energy displaced at the year 2000 for all incentive levels is presented.

Table 8. Summary of Electric Energy Displaced at the Year 2000 for the Commercial Market — Percent.

Scenario	Effective Annual Cost		
	Nominal	Less 25%	Less 50%
	Electrical Energy Displaced, percent		
Gas Curtailment	11	15	21
Historical Growth	0	7	9
Retarded Energy	0	0	0

As expected, the Gas Curtailment Scenario produces the largest solar energy penetration. There is no penetration of solar energy into the electrical energy market under the Retarded Energy Growth Scenario. Under this scenario some buildings do adopt solar energy but all of these adoptions occur in the natural gas submarkets.

C. MARKET DYNAMICS

1. New and Retrofit Markets

In Fig. 6 the market has been segregated into buildings which were retrofitted with solar equipment after final construction and buildings which incorporated solar systems at the building design stage, i.e., "new buildings." In the Gas Curtailment Scenario, without any first cost incentives, only 13% of the buildings which adopt solar energy systems by the year 2000 are from the retrofit market. The retrofit market becomes more important if the first

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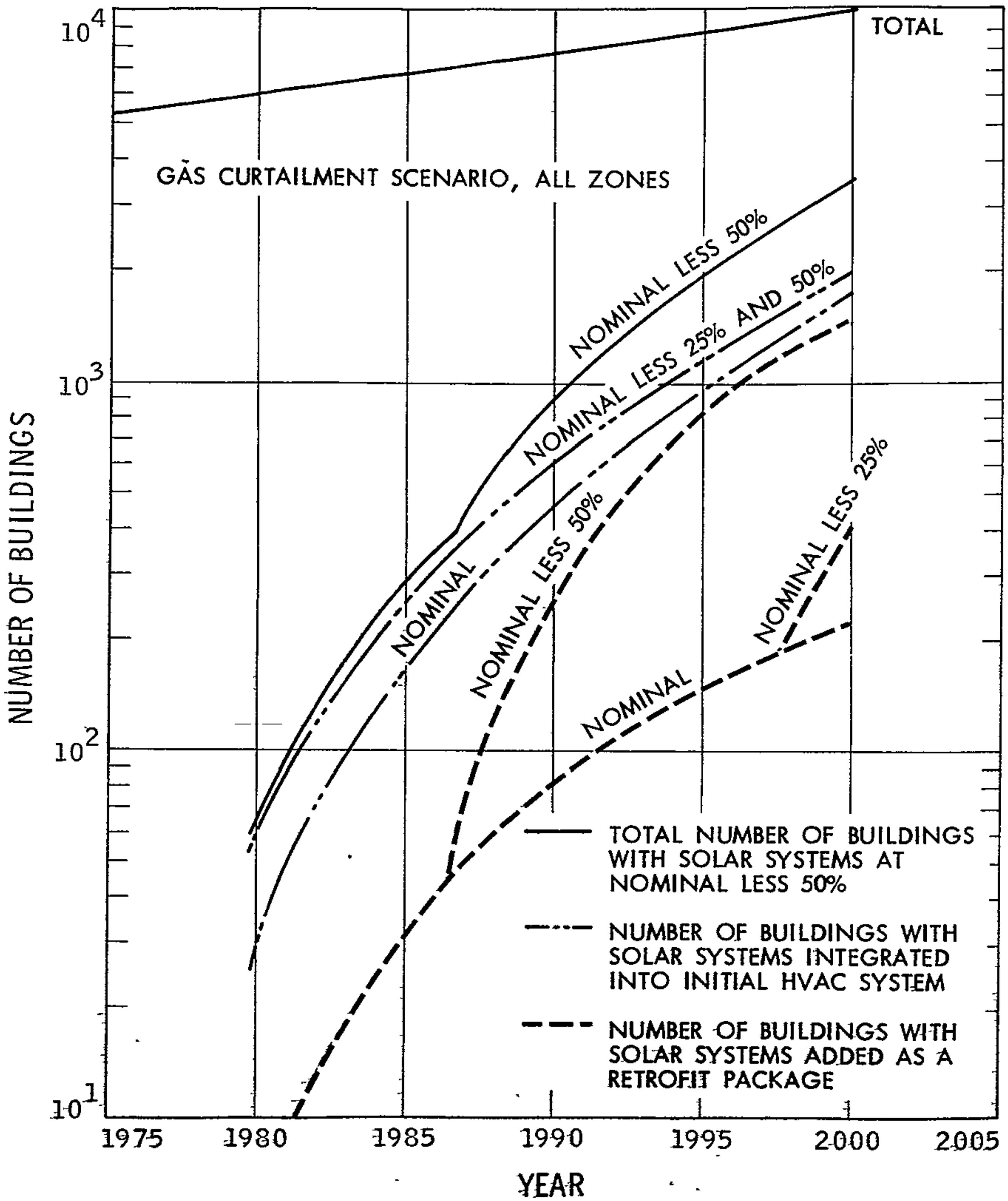

Fig. 6. Growth of New and Existing Office Buildings with Solar Energy Systems.

cost of solar energy systems is cut in half. This level of incentive causes the retrofit market to become more active at an earlier time. By the year 2000, 43% of the buildings which adopt solar energy systems are from the retrofit market in the Gas Curtailment Scenario.

The penetration criterion used in this analysis produces two characteristics in building penetration numbers. When the criterion is satisfied and penetration begins, the retrofit market will typically yield a large number of building candidates. The new building market, however, only exposes those buildings which are entering the market at each given year. If a new building does not have a solar system installed during its birth, then that building becomes a candidate in the year following for a retrofit package. Therefore, each year, the new building population remains small while the existing or old building population continually grows. Small rates of penetration into a large number of existing buildings will produce large numbers of building modifications and the slope discontinuities in the curves of Fig. 6. The new building solar modifications will tend to build more smoothly because at each year a relatively small and consistent number of buildings are candidates.

2. Effect of First Cost Incentives

The various levels for effective cost of solar energy systems can be interpreted as incentives applied to first cost. The commercial market illustrates some of the market effects of first cost incentives that are implicit in the simplified model of the market used in this study. Some of these market effects could also be expected to occur in the real world.

In the new building office market, a 25% incentive advanced the penetration of solar energy systems by 1.5 years (cf. 7 years for the single family market), whereas the 50% incentive does not advance the time of market penetration any further. This is in contrast to the single family market where the effect of increasing the level of incentive is a more of less proportional advancing of the date to reach a significant level of penetration. In the office building case the 25% incentive is more than enough to cause the criteria for adoption to be met immediately. Since the market penetration rate is postulated to be limited by other factors, the higher level of incentive is not effective in increasing the penetration.

If incentives are adequate to activate the retrofit market, large increases in the utilization of solar energy are possible. The "nominal less 50%" case in Fig. 6 illustrates this point. Because the retrofit market is potentially large, even small rates of market capture can be important.

3. Comparison of Microclimatic Zones

Large commercial buildings are relatively insensitive to environment, but some differences in displaced energy can be observed in the three microclimatic zones (see Table 9).

Table 9. Comparison of Displaced Electrical Energy in the Commercial Market.*

Effective First Cost	Zone		
	Beach	Inland Valley	High Desert
Nominal	8**	13	11
Nominal less 25%	12	16	14
Nominal less 50%	17	23	19

*Gas Curtailment Scenario Year 2000.
**Percent of total used in the zone for thermal functions.

The Inland Valley Zone reflects a more favorable solar energy cost and displaces the largest fraction of HVAC electric energy. In the Historical Growth Scenario, lower fractions of displaced energy were observed but the Inland Valley Zone continued to be relatively the most attractive. Since this zone contains the majority of office buildings (59%), the greatest energy impact will also be made in the Inland Valley Zone.

4. Market Split by System

Seven specific conventional HVAC systems were considered in the commercial market. These seven systems are listed in Appendix B. The solar systems which were designed to compete with these conventional systems can be grouped into three categories (listed in order of economic desirability):

1) A solar-augmented hydronic heat pump
2) A complete solar heating, cooling, and water heating system
3) A solar cooling system.

Without any incentive provided, the solar-augmented heat pump immediately begins to penetrate all of the markets in which it can be considered a competitor. However, the energy displaced by this system is small since it supplies only part of the heating load of the building, and the heating load is small compared to the air conditioning load. In addition the basic hydronic heat pump system is a relatively new system and has yet to gain a significant place in the market. The ultimate penetration level for this system is therefore primarily a function of the number of buildings which are postulated to adopt the basic hydronic heat system.

"Solar cooling only" systems were postulated to be competitors only in buildings using electric terminal reheat. Since terminal reheat along with dual duct systems were postulated to be obsolete under all scenarios, this meant that "solar cooling only" systems did not penetrate the market under any scenario for any level of effective first cost.

The combination solar heating, cooling, and water heating system penetrates the market under the Gas Curtailment Scenario with all levels of effective first cost. This system only penetrates the market in the other scenarios if the effective first cost is reduced. This system is compatible with the dual duct system (postulated to be obsolete in new construction), the fan coil system, and the newer variable air volume systems.

Estimated values for the market share of the solar-augmented heat pump and the combination solar energy system in the various conventional HVAC submarkets are tabulated in Table 10 for the three scenarios with the assumption of a 50% effective first cost reduction. Maximum penetration levels of 43% occur in the new markets for the heat pump and the combined system. Retrofitting dual duct systems is attractive in all but the Retarded Growth Scenario. Solar energy systems penetrate the all-gas market in both the Historical Growth Scenario and the Retarded Growth Scenario.

Table 10. Competition of Solar Energy Systems with Various Conventional HVAC System: Market Share in the Year 2000.

Conventional HVAC System	Percent of Buildings Adopting Solar					
	Gas Curtailment		Historical Growth		Retarded Growth	
	New	Old	New	Old	New	Old
All Gas	0	0	13	28	29	0
Dual Duct	0	26	0	4	0	0
Variable Air Volume and Fan Coil	42	11	43	0	0	0
Heat Pump	43	14	32	17	32**	0

*Inland Valley, incentive of 50%.

**Systems with gas boilers only.

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APPENDIX A

MARKET CAPTURE ASSUMPTIONS IN NSF PHASE O REPORTS

by

A. S. Hirshberg

APPENDIX A

MARKET CAPTURE ASSUMPTIONS IN NSF PHASE O REPORTS

by A. S. Hirshberg

A. INTRODUCTION

The three NSF Phase O reports (Refs. 1, 2, 3) incorporate different assumptions regarding market capture. Although the assumptions at first glance appear to be similar qualitatively, a detailed analysis indicates that the assumptions results in quite different function penetrations. This helps explain the wide and paradoxical differences between the estimates of total market capture in the year 2000 by the three contractors.

The actual estimates of market capture in the year 2000 range from a low of 0.6 billion dollars by TRW to a high of 16 billion dollars by General Electric. This difference of a factor of 30 is surprising enough; however, when one considers that GE assumes lower conventional fuel prices, a later initial penetration date, and no retrofit of existing buildings, whereas TRW assumed the opposite, the penetration results appear paradoxical and confusing. (They used comparable costs for the solar systems.) This paradox can be partly resolved by analyzing the operational differences in the logic for the market capture assumed by each contractor. Such an analysis can also motivate the logic behind the assumptions adopted for the BASE (Building Application of Solar Energy) study, since the Phase O reports as a whole were one of the important starting points used by BASE. (Others include separate studies of the building industry and the diffusion of innovations — by Hirshberg and Schoen, 1974.)

Each of the contractors incorporated a two-step logic into their market capture assumptions. The first is an economic criterion which indicated the point at which an "economically rational"[1] man would find the substitution

[1] For interesting (and conflicting) analyses of the meaning of economic rationality see K. Arrow, Social Choice and Individual Values, New Haven: Yale Press, 1963; M. Olson, "The Logic of Collective Action," New York: Schocken Brooks, 1971, and K. Boulding, "The Ethics of Rational Decision," Management Science, 12, Feb. 1966, pp. 161-169.

(investment) of solar energy system for conventional fuel acceptable. The second is a penetration process which accounts for the growth of solar energy sales and hence its adoption for heating and cooling of buildings.

B. TRW

The TRW assumptions for market capture are a bit confusing. The logic described in the summary volume, partly conflicts with the description in the backup Volume 1 under market capture, which includes two different processes for the decision logic (present value decision by the single family homeowner, both new and retrofit, and ROI decision by the other submarket "decision makers"). Basically, they assumed a normal or Gaussian curve which specified the density of the penetration rate as a function of solar energy system (SES) return on investment (ROI). The parameters of the normal curve ($\overline{X}$, the average; and σ, the standard deviation) are determined from two simultaneous equations. These equations are determined by assuming that a 10% SES ROI will yield X% penetration rate and at 20% SES ROI will yield a Y% penetration rate. X and Y and justified based upon a survey of potential buyers of SES in three cities, although just how the survey results yield these estimates is never made clear. The integral of the normal curve with the estimated parameters ($\overline{X}$, σ) from $-\infty$ to the actual SES ROI yields the penetration rate. This specifies the penetration rate prior to 1990. After 1990 the rate is changed by assuming minimum ROIs for payback periods of 5 years. The following summarizes the TRW logic:

<u>For the Single Family Market</u>

Decision criterion before 1990 — Annual Fuel Savings (A_j) ≥ Mortgage Payments (MP_j) - Maintenance (M_j).

This is the same as Eq. (1), Section III, except that the SES cost (FC) is reduced by a 12% down payment the first year. TRW assumes that at equality, this yields a 1.5% penetration rate and, at $A_j = 2(MP_j - M_j)$, the penetration rate is 5 or 10%.

Decision criterion after 1990 — Require a payback period of 5 years to determine ROI, which then specifies the penetration rate.

All Other Submarkets

Decision cirterion — The SES ROI is calculated by assuming the requirement for a 5-year payback period so that:

$$\text{ROI} \frac{(1 + \text{ROI})^5}{(1 + \text{ROI})^5 - 1} = S_j$$

where

$$\text{Net Annual Savings } (S_j) = \begin{cases} \text{Annual Fuel Savings } (A_j) \\ - \text{ SES Annual Mortgage Payments } (MP_j) \\ + \text{ Maintenance } (M_j) \end{cases}$$

and

$$(MP_j) = C_j - .25\, C_j, \text{ i.e., after a 25\% down payment.}$$

The market penetration rate was calculated from a second Gaussian curve with a 1.5% capture rate at a 5-year 10% ROI.

The TRW logic is appealing. Market penetration is made an explicit function of ROI and presumably the functional form of penetration with ROI is determined by empirical questionnaire results for two points on the curve. (The points on a normal curve specify the parameters $(\overline{X}, \sigma)$ and hence the curve.) However, because the logic switches to a 5-year discounted ROI criterion after 1990 and because ROI criterion tends to be more stringent than present value criterion (cf. Section III), the TRW logic gives lower penetration rates after 1990 than before, even though the intent seems to be the opposite. That is, they argue that, prior to 1990, SES will be perceived as an untried product with a (presumably) more stringent decision criterion than after 1990. But their operational logic produces just the reverse as can be seen by examining the lower slope of the capture curve after 1990. This in part explains their paradoxial lower impact, even though they assume retrofit of buildings (particularly apartments) with SES systems will occur and that some penetration will occur for SES during 1975. (They are the only ones who assume this.)

C. WESTINGHOUSE

The Westinghouse market capture logic is similar to the TRW logic but different in detail. Unlike TRW their decision criterion is separated from their penetration rate projection. The decision criterion involves an investment decision and solar systems are purchased if and when the marginal investment in the solar energy system is less than the marginal savings of the fuel. This is similar to the TRW present value decision criterion. However, the Westinghouse method is different in detail. They assume 15-year lifetimes and 8% interest rates for loans in the solar equipment. They also assume a yearly 3% escalation in the price of fuel. They use these assumptions to determine a multiplier P which equates the annual fuel cost (AFC) to what they call a fuel alone cost equipment which equals the annual fuel saved by a 100% solar system. Thus, FACE = P • AFC. The multiplier P is calculated from a set of constrained equations (which are incorrect as given in the report but which can nonetheless be deciphered).

$$r\left(P_o - \sum_{i=1}^{k-1} P_i\right) + P_k = F_o \cdot \prod_{i=1}^{k} (1 + f_i), \text{ for } k = 1, 2, \ldots n$$

$$\sum_{i=1}^{n} P_i = P_o$$

where P_o = the principal amount of the solar equipment (C_j) and the multiplier $P = P_o/F_o$ (which is incorrectly stated in the report). This equation basically constrains the annual maintenance free mortgage cost of the solar system to be equal to the escalated cost of the fuel conserved, F_o, escalated at a rate f_i each year.

The resulting P is used to calculate a FACE for a solar system. For example, the fuel cost for heating in Atlanta, Georgia, is given by Westinghouse as $293 per year (using oil). The calculated multiplier P = 10.164 and the FACE is $2978 which specifies the equivalent cost of a 100% solar heating system. (Their calculations are further disaggregated to account for the mixes of different fuels used in each part of the country.)

Given the FACE value, they define a solar economic ratio (SER) which is the incremental cost of the solar equipment (C_j) divided by a marginal reduction in conventional fuel expense (fraction supplied by solar f_j times FACE):

$$SER = \frac{C_j}{(f_j) \cdot (FACE)}$$

The SER can be used for a senstivity analysis by reducing C_j to the cost of the various components from collectors to convectors; hence, the variation of SER with advances in solar technology and reduced costs can be examined.

Their market penetration is straightforward. They assume linear relationship between market share and SER with three different relationships assumed (one for single family, one for office and stores, one for apartments). For commercial structures the SER logic was modified to required 8% discounted ROI with 25-year lifetimes, income tax brackets of 50%, 3% fuel escalation, and 5 year depreciation (accelerated). This yields P = 12 for apartments, stores, and offices as opposed to about 10 for single family.

The upper bound penetration (market share) is assumed to be 60% for single family and apartments and 50% for stores and offices; apparently no retrofit was allowed. These penetrations are assumed to occur when SER reaches 0.5 for single families and 0.25 for the others. This really means that maximum capture occurs when the marginal savings of solar energy (as adjusted by the multiplier, which accounts for amortization and fuel escalation) exceeds the incremental equipment cost by a factor of 2 or 4, respectively. Figure A-1 shows these penetration curves.

The Westinghouse approach is an accepted method used by other industrial companies. Basically, it allows for ROI and payment stream calculations. However, the assumed relationships of market shared to the solar economic ratio is not substantiated within the Phase O report. It is apparently based on experience with other products.

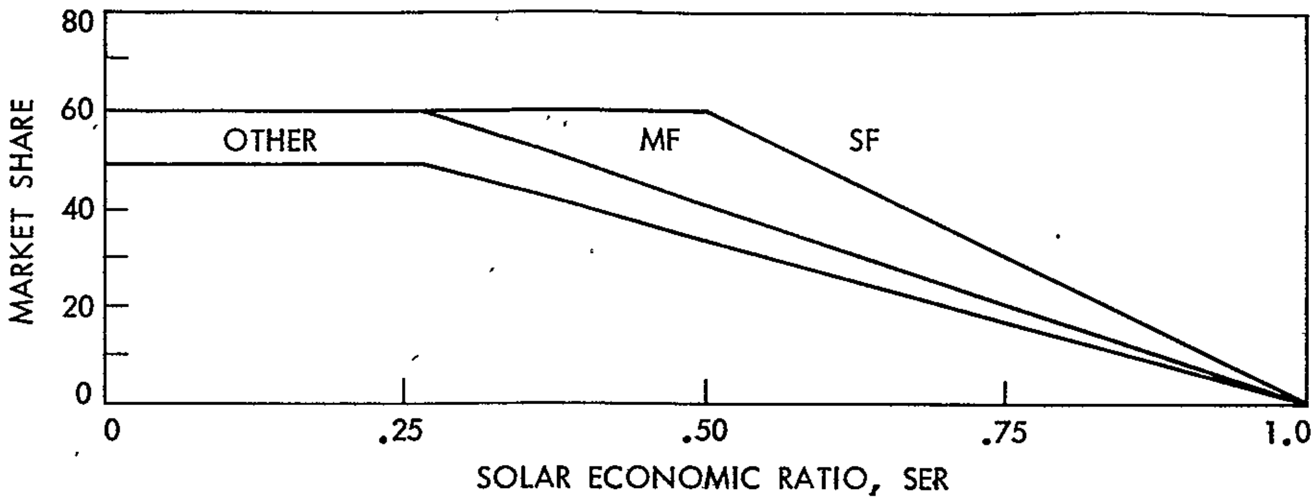

Fig. A-1. Market Share.

D. GENERAL ELECTRIC

The GE capture method is different from either of the other two. GE does does not appear to incorporate any decision criterion for the basic start of the adoption of solar systems. The penetration calculations are separated from the cost analysis (apparently because of time constraints). The penetration analysis uses the Fisher-Pry function to determine the total capture of solar energy systems as a function of time. GE assumes that the rise time for the penetration curve can be affected by government action and their baseline case uses a $\Delta t = 15$ years (not terribly short compared to the historical lag times in the building industry). GE assumes no retrofit for their baseline case, a 65% upper bound for new single family penetration, and a 75% upper bound for new multi-family and new commercial. The most critical parameter (given the penetration logic used) is the date at which 1% penetration occurs, which is equivalent to specifying t_m ($t = t_{90\%} - t_{10\%} + t_{50\%} - t_{1\%}$) (personal communication with W. Hauz). GE arbitrarily uses 1985 as the year when 1% penetration of new buildings is first reached. Presumably this is based on the cost analysis and some estimate of government actions which might speed the use of solar energy. However, given the functional form of the Fisher-Pry formula, these assumptions mean, operationally, that most of the penetration occurs between 1990 and 2000 (when the curve grows quite rapidly) and there is only a 0.1% penetration

Given the FACE value, they define a solar economic ratio (SER) which is the incremental cost of the solar equipment (C_j) divided by a marginal reduction in conventional fuel expense (fraction supplied by solar f_j times FACE):

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The SER can be used for a senstivity analysis by reducing C_j to the cost of the various components from collectors to convectors; hence, the variation of SER with advances in solar technology and reduced costs can be examined.

Their market penetration is straightforward. They assume linear relationship between market share and SER with three different relationships assumed (one for single family, one for office and stores, one for apartments). For commercial structures the SER logic was modified to required 8% discounted ROI with 25-year lifetimes, income tax brackets of 50%, 3% fuel escalation, and 5 year depreciation (accelerated). This yields P = 12 for apartments, stores, and offices as opposed to about 10 for single family.

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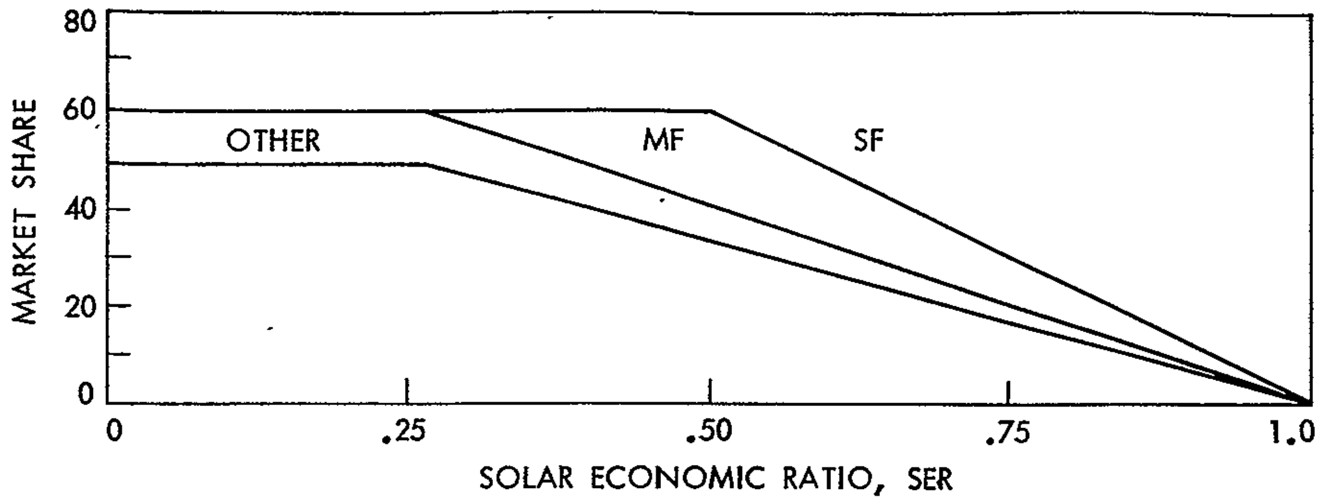

Fig. A-1. Market Share.

D. GENERAL ELECTRIC

The GE capture method is different from either of the other two. GE does does not appear to incorporate any decision criterion for the basic start of the adoption of solar systems. The penetration calculations are separated from the cost analysis (apparently because of time constraints). The penetration analysis uses the Fisher-Pry function to determine the total capture of solar energy systems as a function of time. GE assumes that the rise time for the penetration curve can be affected by government action and their baseline case uses a $\Delta t = 15$ years (not terribly short compared to the historical lag times in the building industry). GE assumes no retrofit for their baseline case, a 65% upper bound for new single family penetration, and a 75% upper bound for new multi-family and new commercial. The most critical parameter (given the penetration logic used) is the date at which 1% penetration occurs, which is equivalent to specifying t_m ($t = t_{90\%} - t_{10\%} + t_{50\%} - t_{1\%}$) (personal communication with W. Hauz). GE arbitrarily uses 1985 as the year when 1% penetration of new buildings is first reached. Presumably this is based on the cost analysis and some estimate of government actions which might speed the use of solar energy. However, given the functional form of the Fisher-Pry formula, these assumptions mean, operationally, that most of the penetration occurs between 1990 and 2000 (when the curve grows quite rapidly) and there is only a 0.1% penetration in 1980. The form of the Fisher-Pry formula combined with $a \cdot \Delta t = 15$ and 1985 as the 1% penetration date causes GE to end up with nearly 30 times the penetration rate for solar energy compared to TRW.

APPENDIX B

NUMERICAL DESCRIPTION OF THE BASIC MARKETS

APPENDIX B

NUMERICAL DESCRIPTION OF THE BASIC MARKETS

A. SINGLE FAMILY RESIDENCE

Table B-1 presents building population, solar system cost numbers, and solar-energy-displaced conventional energy for the single family residence in the three climatic zones. The two left-hand columns show the segregation of the single family residence into basic HVAC systems and the third column indicates allowed solar energy competition or modifications. Data for the Beach Zone is presented on the first page of Table B-1, and for the Inland Valley and High Desert Zones on succeeding pages.

The HVAC system number (first column) is a convenience assignment. The basic system is identified (second column) by a three-letter code. The letters identify the conventional energy source for water heating, space heating, and cooling. Thus G-G-E means a system utilizing natural gas for water heating and space heating and electricity for air conditioning. The absence of a third letter means a system without air conditioning.

One of the assumptions of the study of the single family residence is that all existing electrically heated buildings and all new buildings will be treated as energy-conserving. Existing gas heated buildings are assumed to have 6 inches of insulation in the ceiling and thereby correspond to the standard single family dwelling in Ref. 8. Therefore, in the basic HVAC system list of Table B-1, Systems 2 and 4 were included to specifically account for energy-conserving gas heated buildings which enter the market after 1975. In the analysis, new building additions cause the population of Systems 2 and 4 to grow from zero and old building removal causes the population numbers of Systems 1 and 3 to decrease.

As can be seen in the third column, a variety of solar system modifications is possible for any one of the seven basic HVAC systems. For example, System 6, an all-electric system, may be modified by the addition of solar equipment to heat water, provide space heating, provide both space heating and water heating, and provide absorption cooling or to provide all three functions. The costs and economics of each possible modification is separately evaluated

Table B-1. Single Family Residence.

HVAC System	HVAC* Code	Solar Sytem Addition	Beach Zone			
			1975 Population Number of Buildings	Cost of Solar on New Building - $	Displaced Energy (Kwh/yr)	
					Electric	Gas
1	G-G	none	459,264	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		SH	0	2,915	0	23,233
		WH + SH	0	3,250	0	25,956
2	G-G (Conserving)	none	0	N/A	N/A	N/A
		WH	0	1,153		4,719
		SH	0	960		5,803
		WH + SH	0	1,200		7,621
3	G-G-E	none	30,215	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		SH	0	2,915	0	23,233
		WH + SH	0	3,250	0	25,956
		Abs. C.	0	3,675	1,706	0
		SH + WH + Abs. C.	0	3,675	1,706	23,233
4	G-G-E (Conserving)	none	0	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		SH	0	960	0	5,803
		WH + SH	0	1,200	0	7,621
		Abs. C.	0	3,031	290	0
		SH + WH + Abs. C	0	3,031	290	8,722
5	E-E	none	32,243	N/A	N/A	N/A
		WH	0	1,153	2,690	0
		SH	0	1,100	3,630	0
		WH + SH	0	2,000	6,630	0
6	E-E-E	none	21,582	N/A	N/A	N/A
		WH	0	1,153	2,690	0
		SH	0	1,100	3,630	0
		WH + SH	0	2,000	6,630	0
		Abs. C.	0	3,031	290	0
		WH + SH + Abs. C	0	3,031	5,290	0
7	E-HP-HP	none	30,215	N/A	N/A	N/A
		WH	0	1,153	2,690	0
		Solar Assist HP	0	803	948	0

*HVAC Code — Defines energy source for water heating - space heating - air conditioning.
E — Electric
G — Gas
WH — Water Heat
SH — Space Heat
Abs. C. — Absorption Cooling
HP — Heat Pump

Table B-1. (Contd).

HVAC System	HVAC* Code	Solar System Addition	Inland Valley Zone			
			1975 Population Number of Buildings	Cost of Solar on New Building - $	Displaced Energy (Kwh/yr) Electric	Displaced Energy (Kwh/yr) Gas
1	G-G	none	600,922	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		SH	0	2,800	0	22,035
		WH + SH	0	3,250	0	24,779
2	G-G (Conserving)	none	0	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		SH	0	1,400	0	6,842
		WH + SH	0	2,000	0	11,394
3	G-G-E	none	121,775	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		SH	0	2,800	0	22,035
		WH + SH	0	3,250	0	24,779
		Abs. C.	0	3,770	2,200	0
		SH + WH + Abs. C	0	3,770	2,200	22,035
4	G-G-E (Conserving)	none	0	N/A	N/A	N/A
		WH	0	1,153	0	4,719
		WH	0	1,400	0	6,842
		WH + SH	0	2,000	0	11,394
		Abs. C.	0	3,031	1,633	0
		SH + WH + Abs. C.	0	3,031	1,633	8,947
5	E-E	none	45,230	N/A	N/A	N/A
		WH	0	1,153	2,690	0
		SH	0	1,400	3,900	0
		WH + SH	0	2,000	6,495	0
6	E-E-E	none	86,982	N/A	N/A	N/A
		WH	0	1,153	2,690	0
		SH	0	1,400	3,900	0
		WH + SH	0	2,000	6,495	0
		Abs. C.	0	3,031	1,633	0
		WH + SH + Abs. C	0	3,031	6,733	0
7	E-HP-HP	none	121,775	N/A	N/A	N/A
		WH	0	1,153	2,690	0
		Solar Assist HP	0	895	1,186	0

*HVAC Code — Defines energy source for water heating - space heating - air conditioning.
E — Electric; SH — Space Heat
G — Gas; Abs. C. — Absorption Cooling
WH — Water Heat; HP — Heat Pump

Table B-1. (Contd).

HVAC System	HVAC* Code	Solar Sytem Addition	High Desert Zone			
			1975 Population Number of Buildings	Cost of Solar on New Building - $	Displaced Energy (Kwh/yr) Electric	Displaced Energy (Kwh/yr) Gas
1	G-G	none	59,818	N/A	N/A	N/A
		WH	0	1,153	0	4,649
		SH	0	5,000	0	36,346
		WH + SH	0	5,150	0	39,436
2	G-G (Conserving)	none	0	N/A	N/A	N/A
		WH	0	1,153	0	4,649
		SH	0	2,800	0	17,396
		WH + SH	0	3,250	0	20,516
3	G-G-E	none	21,365	N/A	N/A	N/A
		WH	0	1,153	0	4,649
		SH	0	5,000	0	36,346
		WH + SH	0	5,150	0	39,436
		Abs. C.	0	6,300	3,899	0
		SH + WH + Abs. C	0	6,300	3,899	34,524
4	G-G-E (Conserving)	none	0	N/A	N/A	N/A
		WH	0	1,153	0	4,649
		SH	0	2,800	0	17,396
		WH + SH	0	3,250	0	20,516
		Abs. C.	0	4,340	2,433	0
		SH + WH + Abs. C	0	4,340	2,433	18,596
5	E-E	none	4,273	N/A	N/A	N/A
		WH	0	1,153	2,650	0
		SH	0	2,800	9,916	0
		WH + SH	0	3,250	11,694	0
6	E-E-E	none	15,260	N/A	N/A	N/A
		WH	0	1,153	2,650	0
		SH	0	2,800	9,916	0
		WH + SH	0	3,250	11,694	0
		Abs. C.	0	4,340	2,433	0
		WH + SH + Abs. C	0	4,340	13,033	0
7	E-HP-HP	none	21,364	N/A	N/A	N/A
		WH				
		Solar Assist HP				

*HVAC Code — Defines energy source for water heating - space heating - air conditioning.
E — Electric; SH — Space Heat
G — Gas; Abs. C. — Absorption Cooling
WH — Water Heat; HP — Heat Pump

in each year of the analysis and the decision to adopt any modification is evaluated on the basis of ROI.

The optimum solar system size is dependent upon the climatic zone of the building. Costs and energy savings will vary between zones. In Table B-1, the three principal microclimatic zones are shown. In each zone will be found a 1975 building population distribution, solar system initial cost, and the energy displaced by the solar system. To illustrate, consider System 4 in the Beach Zone. At the time of initial building construction a solar system providing water and space heating, as well as air conditioning, can be installed for an add-on cost of $3031. Such a system will displace 290 kWh per year of electrical energy and 8722 kWh per year of natural gas energy. The displaced energy numbers refer to energy use. Air conditioning COPs and gas burner efficiencies have been included to translate building thermal load requirements to energy at the meter.

In general, a solar system installation made during the construction of a building will be less costly than retrofit installation on an existing building. To reflect this, all retrofit costs were judged to be 25% greater than Table B-1 values.

From Table B-1, the costs of solar systems and the energy displaced is clearly seen to be sensitive to the type of HVAC system and to the climatic zone. The ROI is not as obvious and can only be determined after the basic energy costs are combined with the displaced energy. Three scenarios with different basic energy cost projections have been analyzed as Cases 1, 2, and 3. These scenarios are discussed in Section II. Figures B-1, B-2, and B-3 translate the scenarios into actual energy costs.

In addition to the energy costs, implementation of the scenarios requires information on the market share captured by each of the basic HVAC systems in new buildings. From the scenarios, a fractional distribution of new buildings by HVAC system has been conceived and is shown for the Beach Zone in Figs. B-4, B-5, and B-6. (Other zones differ moderately because of higher ratio of air conditioned buildings.)

Figures B-4, B-5, and B-6 portray distribution of new buildings by HVAC system and by year. For example, in Fig. B-4 in 1975, 60% (0.6) of the new 1975 buildings will have HVAC System 2 and 35% (0.95 - 0.6) of the new buildings

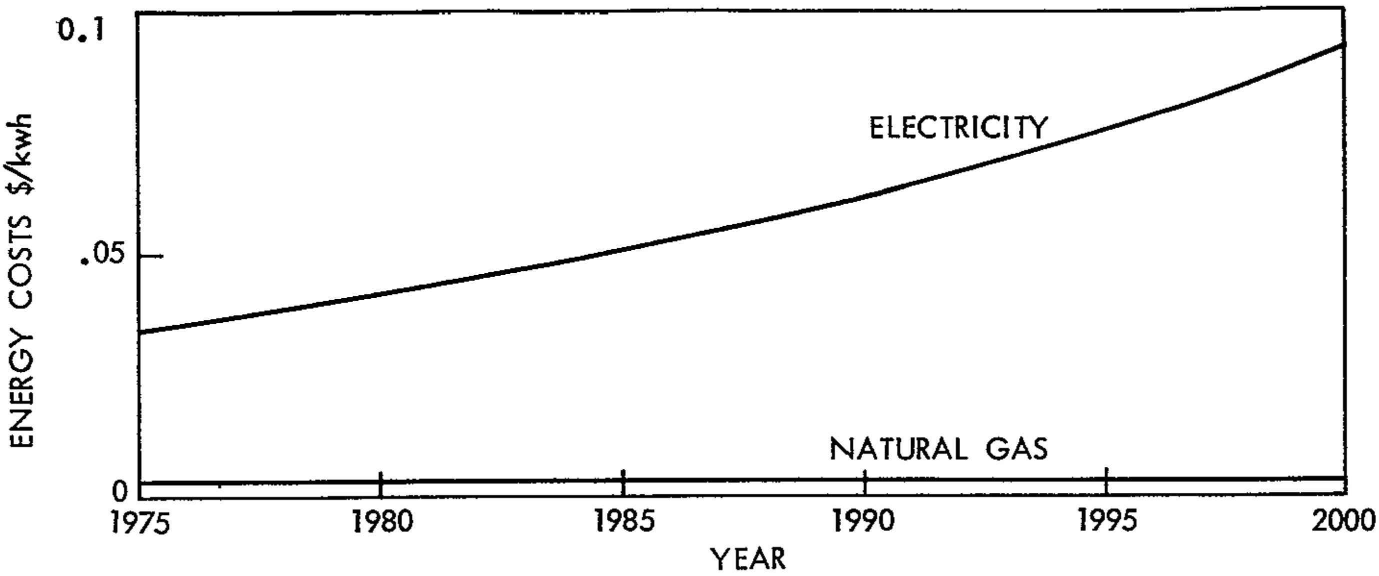

Fig. B-1. Energy Cost Projection for Single Family Residence for Gas Curtailment Scenario, Case 1.

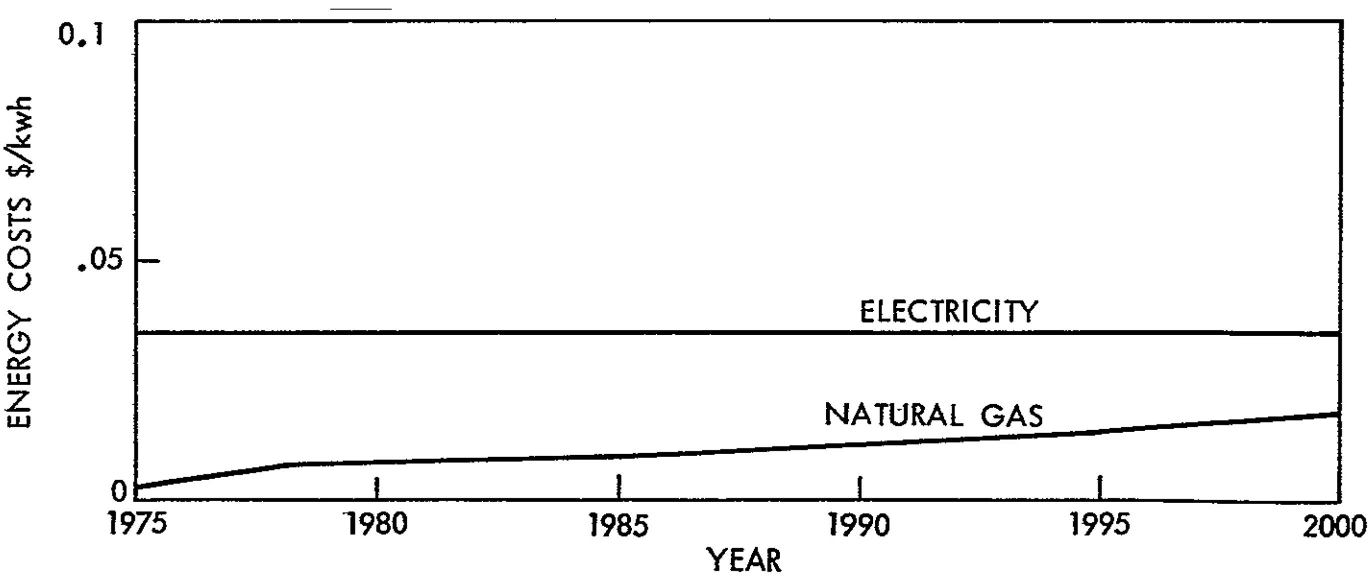

Fig. B-2. Energy Cost Projection for Single Family Residence for Historical Growth Scenario, Case 2.

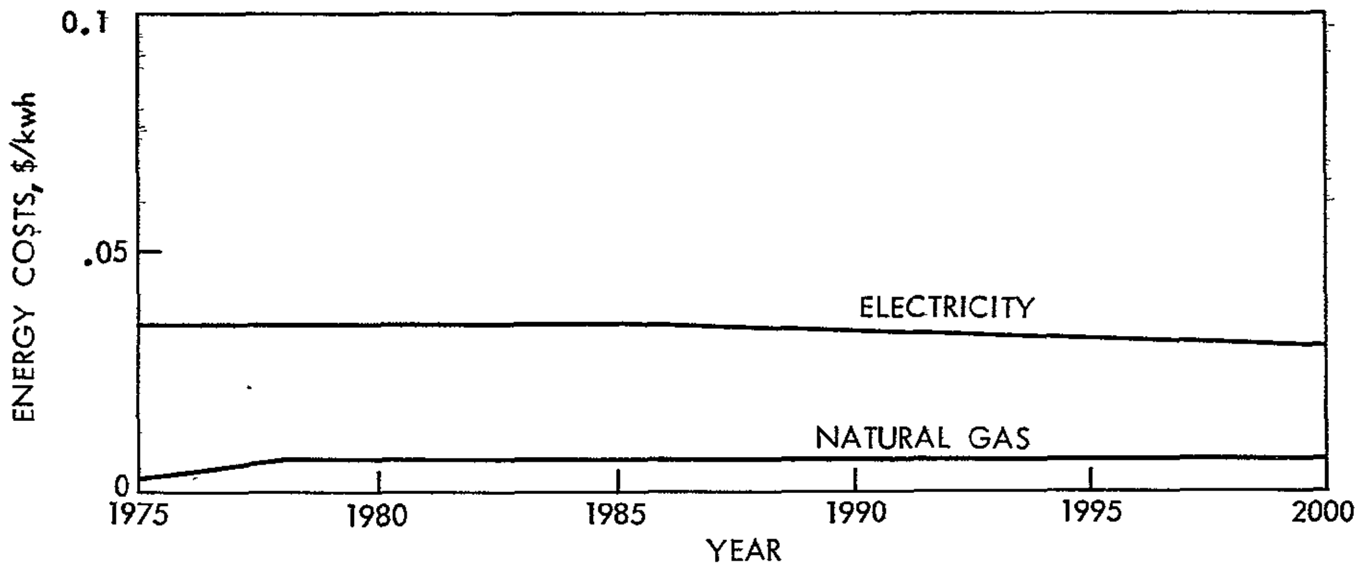

Fig. B-3. Energy Cost Projection for Single Family Residence for Retarded Energy Growth Scenario, Case 3.

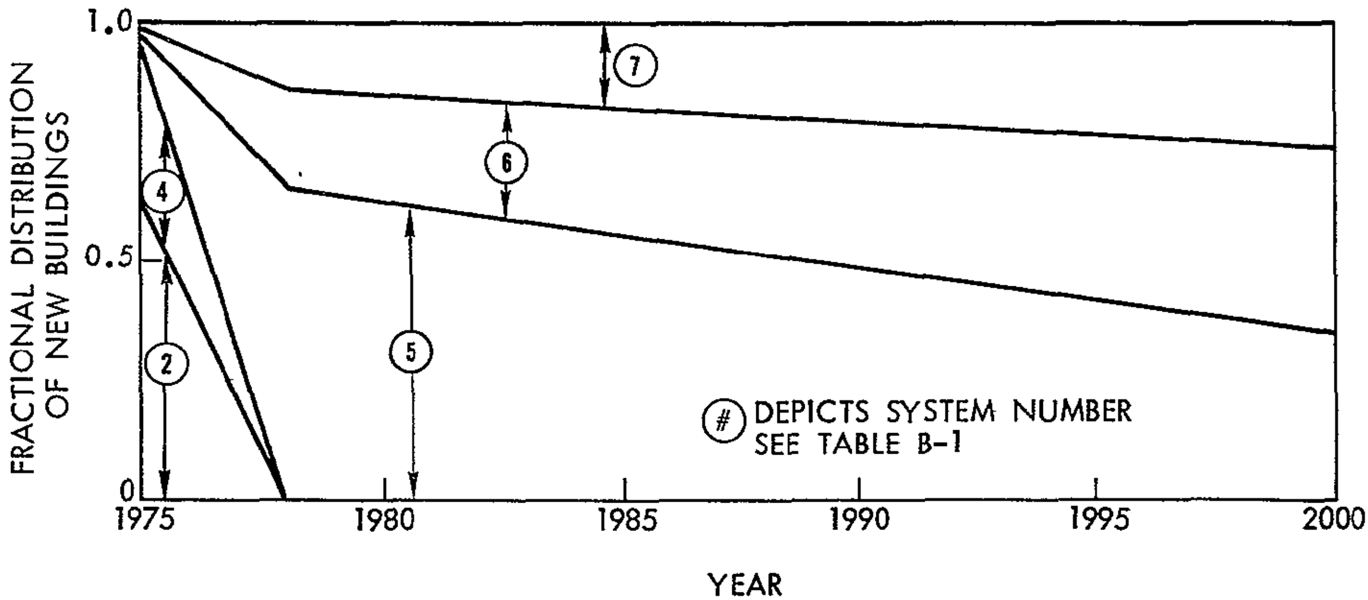

Fig. B-4. New Single Family Residence Distribution by HVAC for System Gas Curtailment Scenario, Case I, Beach Zone.

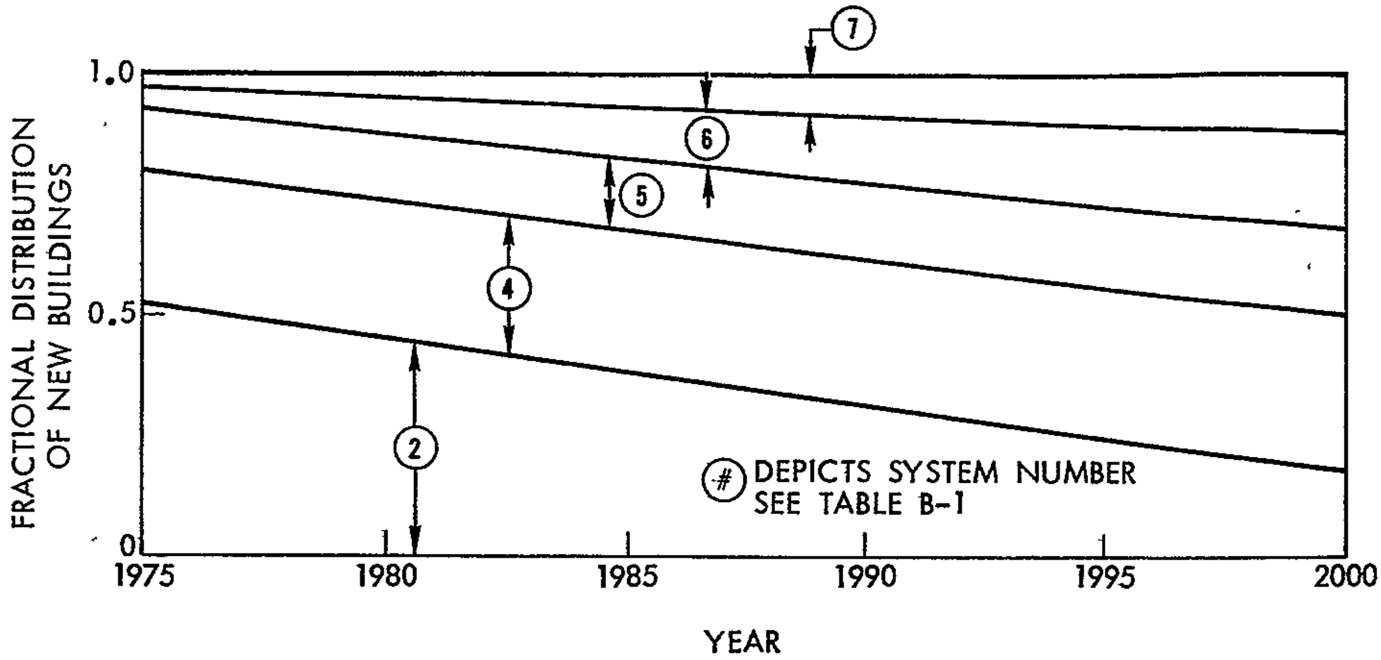

Fig. B-5. New Single Family Residence Distribution by HVAC for System Historical Growth Scenario, Case 2, Beach Zone.

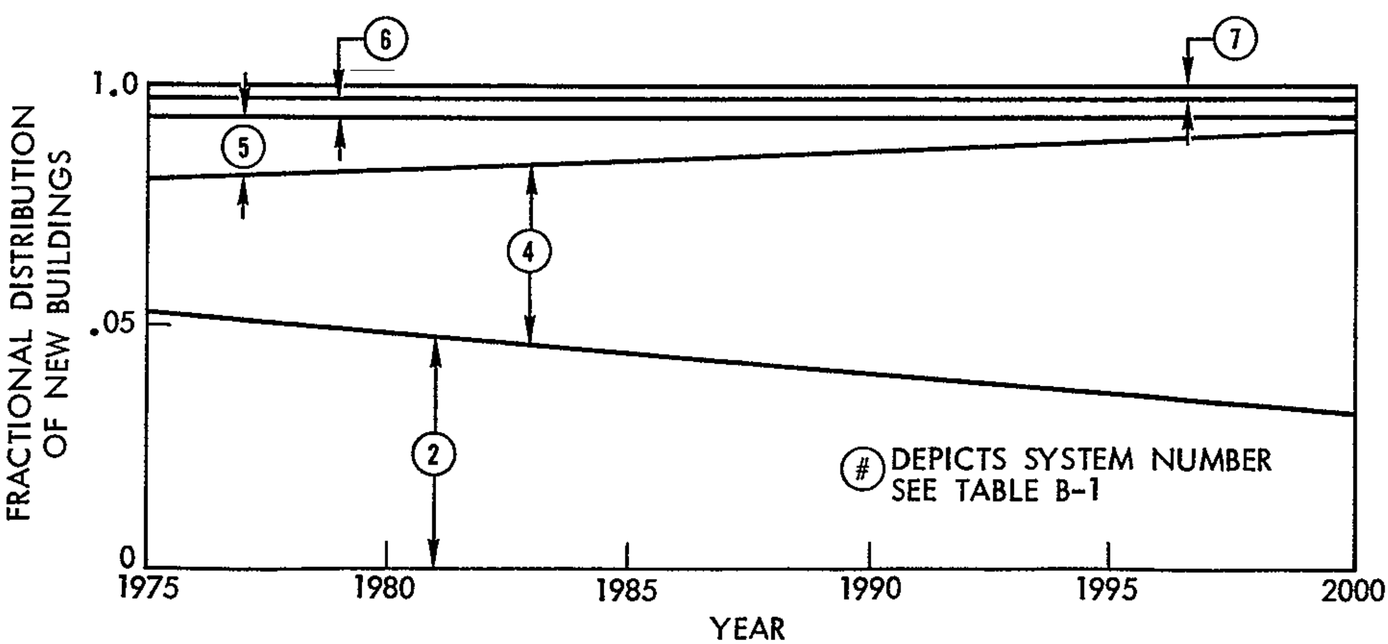

Fig. B-6. New Single Family Residence Distribution by HVAC for Retarded Energy Growth Scenario, Case 3, Beach zone.

will have HVAC System 4. Systems 1 and 3 are absent from all figures because they reflect standard nonconserving buildings and no new buildings are added to the nonconserving population.

In Fig. B-4, the Gas Curtailment Scenario is achieved by forcing all new building into the all-electric market. Plotted in the figure is the fraction of new buildings that have HVAC Systems 2, 4, 5, 6, and 7. HVAC System 2 and 4 utilize gas heat and the market fraction of these systems goes to zero in 1978. The market fraction of new all-electric systems (5, 6, 7) increase and accounts for all new buildings after 1978.

Figure B-5 reflects the Historical Growth Scenario and depicts a gradual increase in the electric share of the HVAC market along with a continuing increase in the fraction of buildings with air conditioning. Figure B-6, Retarded Energy Growth Scenario, projects a decrease in the fraction of all-electric buildings, and a substantial increase in the fraction of gas heated and electrically cooled buildings.

B. OFFICE BUILDING

Table B-2 presents population distributions, costs, and energy displacements for the representative office building in the three prominent microclimatic zones. This table is similar to Table B-1. The solar system modification options for the office building are more constrained than those for the single family residence because the principal HVAC function in a large building is air conditioning. The only significant area for solar application is one that includes air conditioning.

Solar system installation costs also forced constraints in the system selection. When retrofit, as opposed to new building installation, was examined, water and space heating functions were deemed impractical on conventional dual duct and electric terminal reheat systems.

An attractive solar assist for a heat pump system was designed and provided as an option. This system has a high return but displaced relatively small amounts of energy.

Table B-2. Office Building.

HVAC System	HVAC* Code	Solar System Addition	Beach Zone			
			1975 Population Number of Buildings	Cost of Solar on New Building - $	Displaced Energy (Kwh/yr)	
					Electric	Gas
1	G-G-G	none	319	N/A	N/A	N/A
		Solar HVAC	0	97,211	0	$10.7 \cdot 10^5$
2	G-G-E	none	763	N/A	N/A	N/A
		Solar HVAC	0	97,211	$1.51 \cdot 10^5$	$1.39 \cdot 10^5$
3	E-E-E (Existing)	none	532	N/A	N/A	N/A
		Solar cooling (retrofit)	0	(1)	$1.51 \cdot 10^5$	0
4	E-E-E (new building with variable air volume)	none	0	N/A	N/A	N/A
		Solar HVAC (new)	0	97,211	$2.56 \cdot 10^5$	0
		Solar cooling (retrofit)	0	(1)	$1.51 \cdot 10^5$	0
5	E-E-E (new building with fan coil)	none	0	N/A	N/A	N/A
		Solar HVAC (new)	0	97,211	$2.56 \cdot 10^5$	0
		Solar cooling (retrofit)	0	(1)	$1.51 \cdot 10^5$	0
6	G-HP-HP	none	160	N/A	N/A	N/A
		Solar assist	0	4,912	0	$5.37 \cdot 10^4$
7	E-HP-HP	none	0	N/A	N/A	N/A
		Solar assist	0	4,912	$4.3 \cdot 10^4$	0

*HVAC Code — Defines energy source for water heating - space heating - air conditioning.
E — Electric
G — Gas
HP — Heat Pump

(1) Retrofit modification only. Cost @ $128,200.
(2) Retrofit modification only. Cost @ $126,900.

Table B-2. (Contd)

HVAC System	HVAC* Code	Solar System Addition	Inland Valley Zone			
			1974 Population Number of Buildings	Cost of Solar on New Building - $	Displaced Energy (Kwh/yr)	
					Electric	Gas
1	G-G-G	none	551	N/A	N/A	N/A
		Solar HVAC	0	99,500	0	$12.2 \cdot 10^5$
2	G-G-E	none	1318	N/A	N/A	N/A
		Solar HVAC	0	99,500	$1.73 \cdot 10^5$	$1.62 \cdot 10^5$
3	E-E-E (Existing)	none	919	N/A	N/A	N/A
		Solar cooling (retrofit)	0	(1)	$1.73 \cdot 10^5$	0
4	E-E-E (new building with variable air volume)	none	0	N/A	N/A	N/A
		Solar HVAC (new)	0	99,500	$2.95 \cdot 10^5$	0
		Solar cooling (retrofit)	0	(1)	$1.73 \cdot 10^5$	0
5	E-E-E (new building with fan coil)	none	0	N/A	N/A	N/A
		Solar HVAC (new)	0	99,500	$2.95 \cdot 10^5$	0
		Solar cooling (retrofit)	0	(1)	$1.73 \cdot 10^5$	0
6	G-HP-HP	none	276	N/A	N/A	N/A
		Solar assist	0	6,019	0	$6.75 \cdot 10^4$
7	E-HP-HP	none	0	N/A	N/A	N/A
		Solar assist	0	6,019	$5.4 \cdot 10^4$	0

*HVAC Code — Defines energy source for water heating - space heating - air conditioning.
E — Electric
G — Gas
HP — Heat Pump

(1) Retrofit modification only. Cost @ $128,200.
(2) Retrofit modification only. Cost @ $126,900.

Table B-2. (Contd)

HVAC System	HVAC* Code	Solar System Addition	High Desert Zone			
			1975 Population Number of Buildings	Cost of Solar on New Building - $	Displaced Energy (Kwh/yr)	
					Electric	Gas
1	G-G-G	none	68	N/A	N/A	N/A
		Solar HVAC	0	104,500	0	$10.5 \cdot 10^5$
2	G-G-E	none	162	N/A	N/A	N/A
		Solar HVAC	0	104,500	$1.49 \cdot 10^5$	$1.38 \cdot 10^5$
3	E-E-E (Existing)	none	113	N/A	N/A	N/A
		Solar cooling (retrofit)	0	(2)	$1.57 \cdot 10^5$	0
4	E-E-E (new building with variable air volume)	none	0	N/A	N/A	N/A
		Solar HVAC (new)	0	104,500	$2.89 \cdot 10^5$	0
		Solar cooling (retrofit)	0	(2)	$1.58 \cdot 10^5$	0
5	E-E-E (new building with fan coil)	none	0	N/A	N/A	N/A
		Solar HVAC (new)	0	104,500	$2.89 \cdot 10^5$	0
		Solar cooling (retrofit)	0	(2)	$1.58 \cdot 10^5$	0
6	G-HP-HP	none	34	N/A	N/A	N/A
		Solar assist	0	9,683	0	$9.13 \cdot 10^4$
7	E-HP-HP	none	0	N/A	N/A	N/A
		Solar assist	0	9,683	$7.30 \cdot 10^5$	0

*HVAC Code — Define energy source for water heating - space heating - air conditioning.
E — Electric
G — Gas
HP — Heat Pump

(1) Retrofit modification only. Cost @ $128,200.
(2) Retrofit modification only. Cost @ $126,900.

Following the data pattern presented under the single family residence, Table B-2 presents population distributions, costs, and energy displacements. Figures B-7, B-8, and B-9 present energy costs for the three scenarios and Figs. B-10, B-11, and B-12 present the new building fractional distributions.

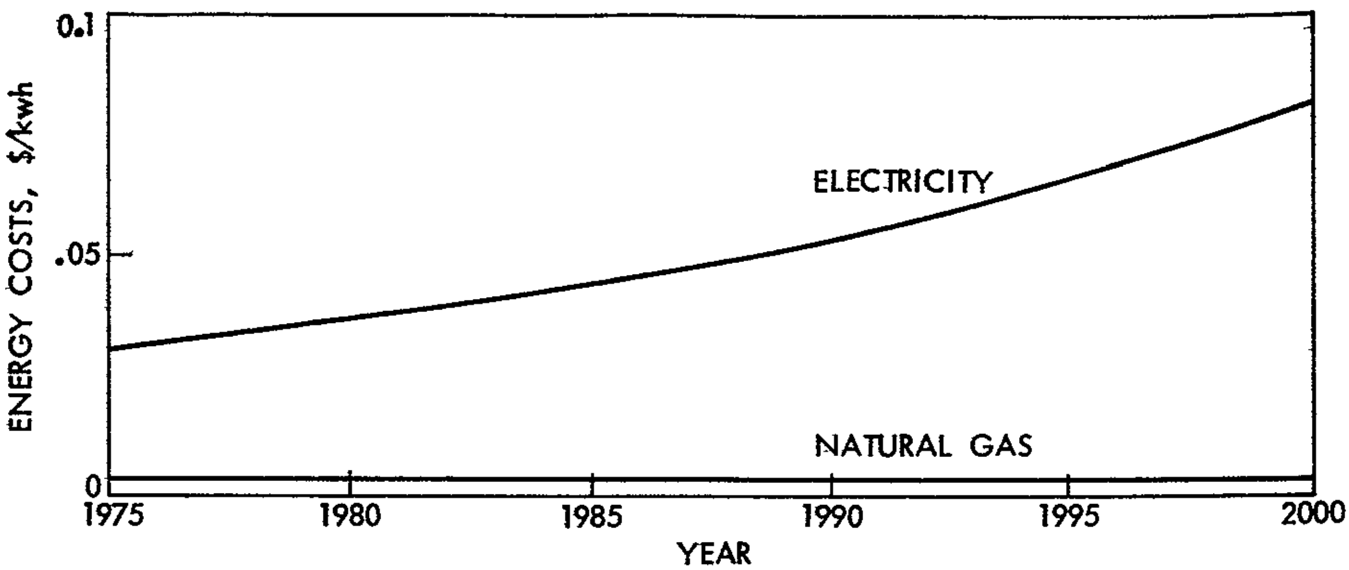

Fig. B-7. Energy Cost Projection for Office Buildings for Gas Curtailment Scenario, Case 1, All Zones.

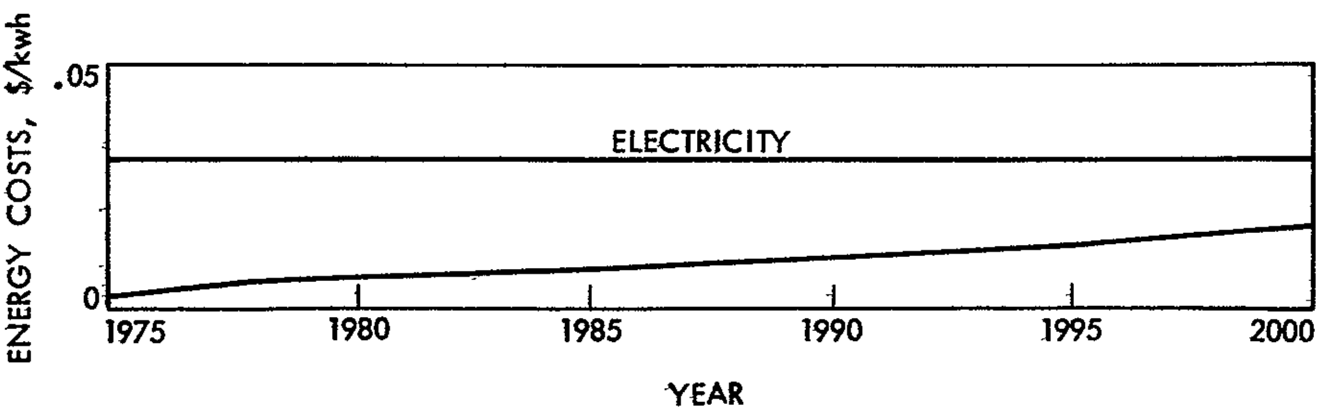

Fig. B-8. Energy Cost Projection for Office Buildings for Historical Growth Scenario, Case 2, All Zones.

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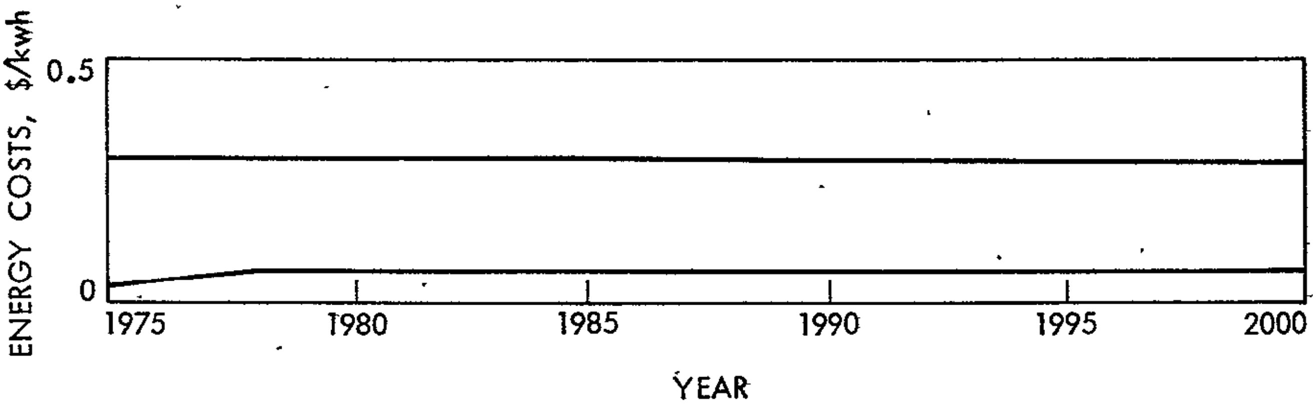

Fig. B-9. Energy Cost Projection for Office Buildings for Retarded Energy Growth Scenario, Case 3, All Zones.

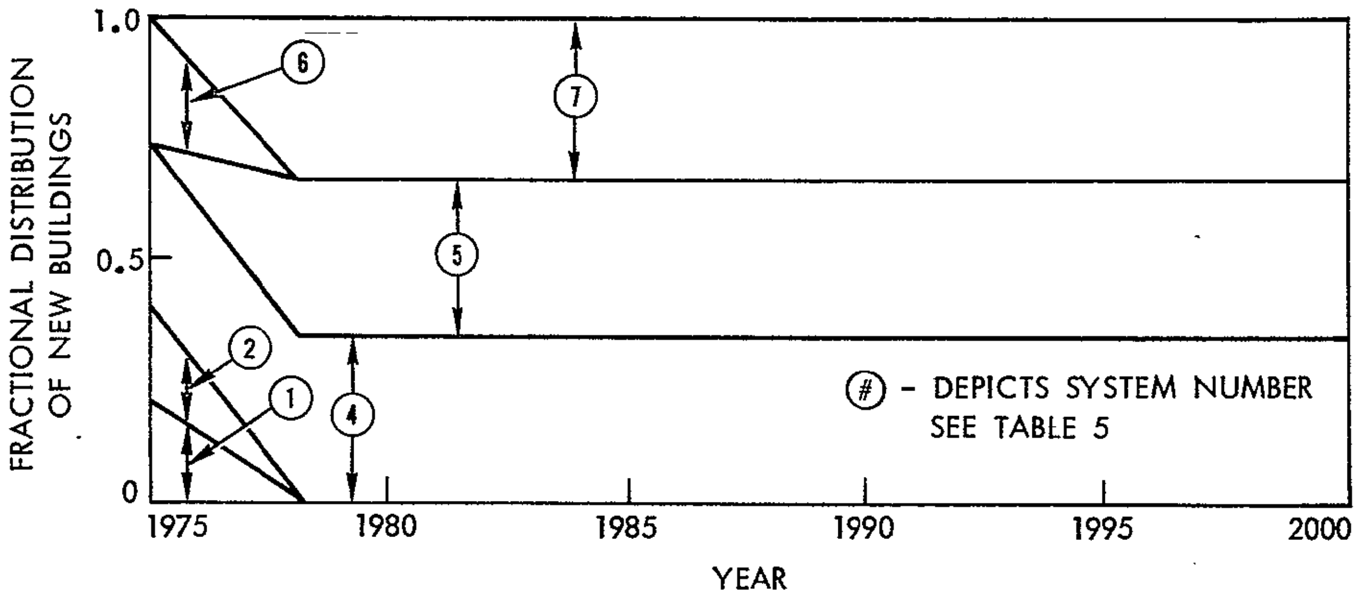

Fig. B-10. New Office Building Distribution by HVAC System for Gas Curtailment Scenario, Case 1, All Zones.

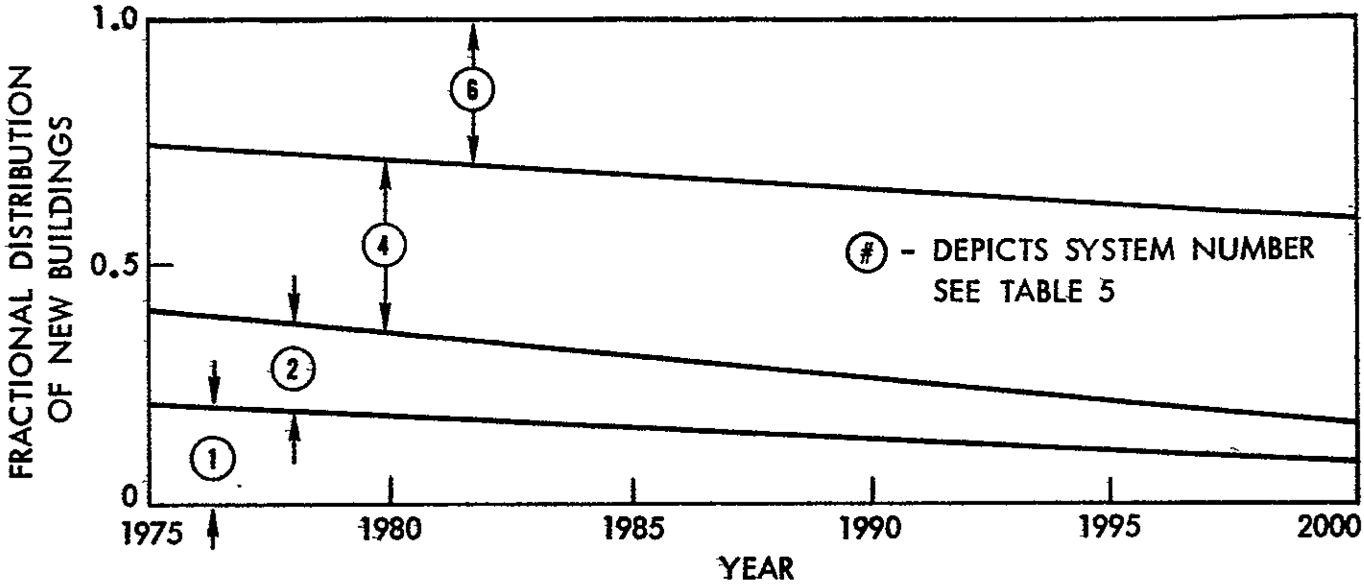

Fig. B-11. New Office Building Distribution by HVAC System for Historical Growth Scenario, Case 2, All Zones.

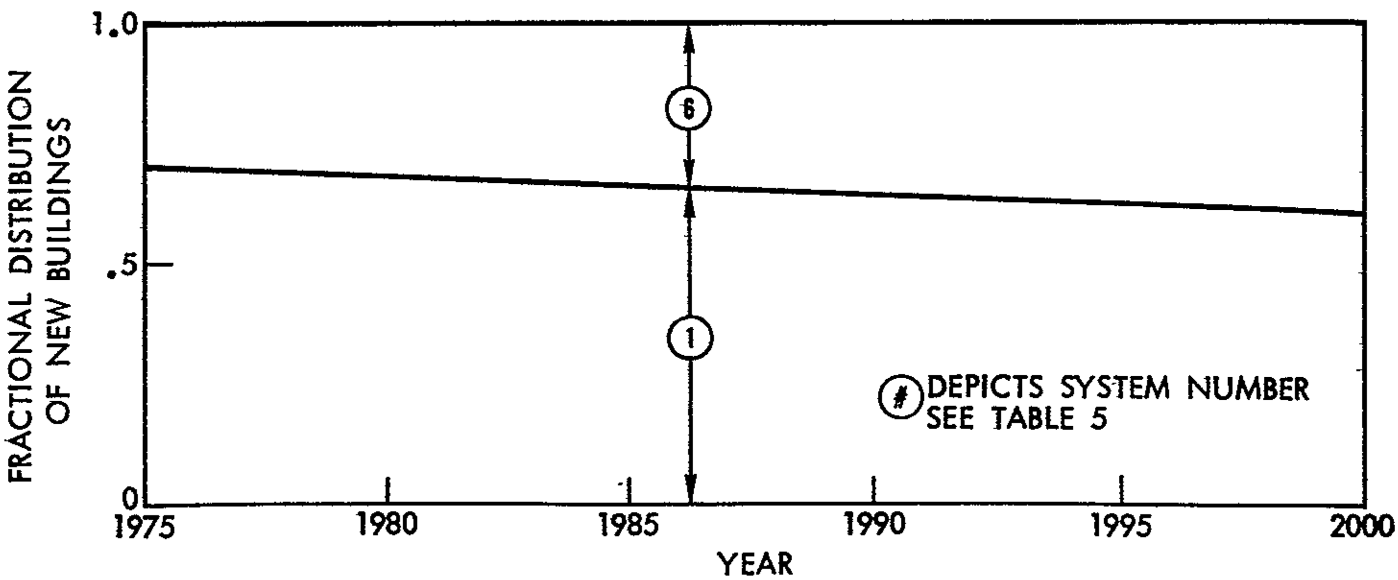

Fig. B-12. New Office Building Distribution by HVAC System for Retarded Energy Growth Scenario, Case 3, All Zones.

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