APPENDIX D– EXHIBIT NO. 1

ASSESSMENT OF SOLAR HEATING AND COOLING FOR AN ELECTRIC UTILITY COMPANY

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I. INTRODUCTION

If commercialization of systems for solar heating and cooling of buildings is to be successful, then consideration of the interaction between these systems and electric utilities is essential. Widespread use of solar heating and cooling systems stands to affect utility generation capacity requirements, fuel requirements, and load factor. Costs of electricity will affect customer decisions regarding installation of solar devices. In the pact, very little thought has been given to how applications of solar energy in buildings can benefit both the operation of an electric utility and the energy user. This paper reports results of a study of applications of solar energy in residential and commercial buildings in the Southern California Edison Company service area. Economic comparison were made which considered both the direct costs and benefits to the utility customer related to the use of solar equipment and the indirect costs and benefits related to effects on the electric utility of demands for back-up electrical energy. Benefits to utility and customer were thus accounted for without any prejudice based on existing institutional arrangements.

The basic objective of the study was to understand the Interaction between elements of the heating and cooling energy supply system well enough

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so that utility objectives and directions for R&D activities in solar heating and cooling could be defined. In pursuit of this objective, it was necessary to: 1) assess the potential impact of solar usage on the utility in question, Southern California Edison, and 2) identify conceptual solar systems having a potential positive societal impact. An a priori assumption of the study was that the magnitude of the impact of solar usage would depend on the cost competitive status of solar equipment, its regional applicability, the number of applicable buildings, and the magnitude of associated loads. Research and development needs are established in cases where the impact can be accelerated and made more positive via solar energy system design.

Just as the cost and availability of electricity will influence the market penetration and design of solar energy systems, solar energy usage for heating and cooling will influence electricity load growth and cost. We will show that solar energy systems are optimally designed when they supply only a fraction, 60-80% of the total heating and cooling energy requirement. Utility electric systems will be affected differently by a load imposed by an all electric heating system than by a load associated with backing up a solar heat source. Since electricity cost is sensitive to the nature of the demand placed upon the electric system, the impact of solar usage on electricity costs can be positive or negative depending upon the design of the solar energy equipment.

Our study was thus a "technology assessment" in that it dealt with a more complete system than is usually considered in evaluating solar heating and cooling systems. To achieve an overall societal benefit by integrating solar devices into this system requires that the total cost of heating and cooling energy be reduced. This total cost is essentially the sum of three components: 1) the cost of the solar equipment, 2) the cost of conventional fuel, and 3) the cost of conventional energy supply equipment (e.g. power plants and transmission and distribution systems). Achieving a reduction in the total cost in general will require that the solar energy systems be designed to operate so that the utility's peak demand is reduced as much or more than its average demand, (i.e. its load factor is improved) and that the proportion of premium fuel usage is reduced. We will have achieved very little if the aggregate cost of installed solar equipment is not offset by the sum of the reductions in the cost of the other two components.

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11. APPROACH TO THE STUDY

Southern California Edison serves 7.5 million people in a climatically divesee area of 50,000 sq. miles as indicated in Figure No. 1. The study confronted a three dimensional problem involving microclimatic zones, buildings, and the heating and cooling systems for the buildings. Our approach was to treat each dimension In turn. Then, with performance and economics calculated for selected systems and selected buildings in selected microclimatic zones, we assessed the market penetration potential of solar energy systems and the sensitivity of this to incentive and economic assumptions.

The study was limited to solar heating and cooling systems for individual commercial and residential buildings. Solar heating and cooling systems designed to serve more than one building were not considered, nor did we consider concepts which use solar energy to generate electricity or concepts using solar total energy systems which provide both electricity and heat.

The first step of the study involved organizing weather data in a way which would allow the estimates of building heating and cooling loads and collector performance to be efficiently and accurately calculated. Our procedure for organizing and using weather data allowed statistically weighting and ordering of different types of days in each month of the year, e.g. hot-cloudy, cold-sunny, hot-sunny, etc. This allowed us to determine the fraction of the total energy requirement that could be served by a given size solar installation. Coat optimum system designs could then be defined. The approach is commended to others as a cost effective strategy for simulating the operation of solar energy systems in buildings; see Reference 1.

Baaed on reduction of data from 14 weather stations in Southern California, five microclimatic zones distinct with respect to solar applications were identified, as indicated in Figure 2.

Applications of solar energy were studied in three of these micro-climatic zones: the coastal zone, the inland zone, and the high desert. The two other zones were not explicitly examined. These zones are the low desert and the San Joaquin Valley. Both have low population levels within the SCE service territory compared to the three zones selected and are similar to the high desert zone.

Four buildings were studied: two residential buildings, a 2250 ft^2 single family, a 9-unit multiple family dwelling, and two commercial buildings: a 6-story, 50,000 ft^2 office and a 145,00 ft^2, 3-story depart-ment store. The buildings all exist in Southern California, and data is available on their actual energy consumption for heating and cooling.

In addition to analyzing the buildings as they exist, separate compu-tations were made for the same buildings as they might be designed in the future baaed on energy conservation oriented design practice. Energy con-servation features were specified for three of the four buildings. This was not done for the department store. The department store had no windows, and the heating and cooling loads in such a building are relatively insen-sitive to the weather.

In total, over 60 combinations of specific solar energy systems for specific buildings with and without energy conservation features in specific locations within the Southern California area were analyzed. The combina-tions of systems and buildings examined are summarized in Figure 3. Per-formance of the solar energy systems was calculated using a generalized multinodal thermal analyzer program (SINDA). Building heat capacities were considered in calculating building heating and cooling demands on an hourly basis. The computer models were calibrated against available heating and cooling load data. For the single family dwelling hourly data was used to calibrate the computer model. For the other buildings monthly and yearly data were used. The model for calculating the solar energy available from any of the collector included both the effect of direct and diffuse solar radiation. A simplified model of the solar energy storage subsystem was used which assumed the storage subsystem to be lossless except for the leas of energy not used on the day it is collected. A discussion of our approach to the use of economic data to assess the potential impact of solar usage in Southern California is contained in Section XI.

III. DATA AND ASSUMPTIONS

The best base data was used. All of the thermal paremeters for the baseline and energy conserving case study buildings are consistent with ASHRAE handbooks. The weather/insolation data developed in Reference 1 were used to drive both building models and solar collection system models. Note that the insolation data of Reference 1 could be low by 15%, thereby making the performance calculation somewhat conservative.

Costs were estimated in constant dollars with 1974 as the base year. The 1974 Dodge Manual and the 1974 National Construction Estimator were used for conventional costs. Costs for unconventional equipment (like solar collectors) were estimated on the assumption that commercial scale production facilities existed for the component in 1974. Implicit in using constant dollars as a base for comparison is the assumption that inflation will affect all components about the same. This assumption is better for some cost factors than others. Specifically, the relationship of electricity cost to the inflation rate cannot be projected accurately. This was taken into account by considering three scenarios for gas availability and electricity price in the market penetration analysis.

In order to make comparisons between solar heating and cooling systems and conventional systems, certain assumptions have been made concerning both conventional and solar technology. Only technology which could be commercially available by 1980 was considered. Solar collectors with efficiencies as good as the beat prototypes currently available were assumed. Heat actuated and vapor compression chillers approaching the practical limits of performance were assumed. This meens that solar energy cooling must compete with electric vapor compression chillers having a C.O.P. of about 3.0 (including condenser fan power), even though vapor compression chillers currently typically fall short of this high performance. Energy was *assumed* to be stored as sensible heat in tanks of water. Although It is theoretically possible **to** store energy as the heat of fusion in various salts and waxes, these storage mediums have yet to be proven practical and economical. The results of the study would not be significantly altered if other storage media were considered.

IV. GENERAL OBSERVATIONS

One way of taking the utility/customer interaction into account in economic analyses is to compare solar energy costs with only the component of total electric energy costs that are actually displaced by solar. In substituting solar energy for electricity, two things can be accomplished. Both have a positive societal impact which can be reflected, imperfectly, in economic terms. First, solar energy can displace the fuels required to generate electricity. The costs of these fuels, as reflected in cents per kilowatt-hour of electricity, can range from a few tenths of a cent per kilowatt-hour for nuclear fuels all the way to two or three cents per kilowatt-hour for various grades of oil used for generation. Second, solar energy end-use systems, when substituted for electric end-use systems, could reduce the load on the electric system at peak times. The demand at these peak times effectively determine the magnitude of the investment in generating and transmission equipment an electric utility must make to reliably serve its customers. If the solar devices operate to reduce heating and cooling related electricity demand during these peak periods, credit can be taken for the costs of increments of electric system capacity rendered unnecessary. As a result of the recent dramatic increases in oil prices, overall capacity and fuel related cost component for the Edison system now have roughly equal weight in determining electricity price.

A solar energy system, having no storage associated with it, could not offset capacity requirements unless the utility load curve and the solar availability curves were uniformly coincident. No situation has been found in which this is the case. Thus, without storage, the value of the solar output is simply the cost associated with the fuel it displaces, which can be thought of as the oil which must be burned to deliver the additional electricity required during the daylight hours. . This value was once thought to be insufficient to afford realistic competitive prospects to any solar heating and cooling application. We find that now with fossil fuel prices greatly impacting the generation cost picture, there are some solar energy systems which appear to be justifiable on their fuel displacement potential alone. Water heating for larger buildings is an example.

In considering solar energy systems that include storage, either intrinsically or by design, the displacement of fuel and capacity depends not only upon the average energy requirement for a system but when the system places the greatest demand on the electric system. Loads which reinforce the overall electric system peak are less desirable than loads which have no time dependence. Water heating is what might be termed a balanced load since it is relatively weather and season insensitive. On an aggregated basis, it contribute both to fuel consumption and the requirements for additional generating capacity. In this case, it is probably appropriate to compare solar costs with the electric billing rate. Electric apace heating, on the other hand, for summer peaking utilities, such as Southern California Edison, could be termed a semi-off-peak load. Note that electricity is not presently the dominant energy source for apace heating in Southern California. Even if it were, solar usage for space heating would have little effect on capacity requirement, and the fuel displaced would be the cheaper fuel involved in utility base load generation. With storage and proper control however, solar augmented heat pump systems would allow the delivery of electric heating energy in a way beneficial to the electric system load factor.

Given the need to analyze solar energy systems from the point of view of the utility and customer combined, it is important to realize that there are a number of alternative means to incorporate favorable or unfavorable impacts on utility econmics into the individual customer's decision-making process. Examples include different rates for peak and off-peak periods and such incentivea as leasing, installation and servicing of preferred systems or other cost sharing on the initial installation. This will require serious consideration in the near future as solar devices begin to penetrate the market.

V. REGIONS

In general, climate affects the optimum size of solar energy system components more than it does the overall economic status of the system. For example, Figure 4 illustrates the difference in economic characteristics of systems sized for the high desert region versus systems sized for the beach in the case of solar hydronic heat pumps. Although the collector area differs by a factor of 3 between zones, differences in the effective solar energy coats are less than 10%.

The relative economic position of solar energy is determined by three factors which vary between zones: (1) the climate, specifically the amount of sunshine, (2) the effect of climate on the utilization factor of the solar equipment, and (3) the economies of scale associated with the total installed cost of solar HVAC systems. For space heating and cooling systems this is seen more clearly in the smeller buildingg, which have weather sensitive heating and cooling loads. For example, in the case of apace cooling, where weather in the inland zone and especially in the desert areas results in a higher utilization factor, economic attractiveness of solar cooling systems does improve as the location moves inland.

On the other hand, in the case of solar space heating of a single family dwelling, the economics are slightly more attractive in the coastal zone. Although the heating load la lower in the coastal zone, it is also more uniform. The more uniform load results in a higher utilization factor on the solar equipment, which more than offsets economies of scale and better solar availability in the inland and high desert areas.

The fact that economics of solar heating are not particularly weather sensitive, in spite of significant climatic variations, is encouraging. The development of broad regional or national markets for solar hardware need not be hindered by the need for geographically specific studies of economic viability.

Energy conservation measures which reduce the size and first cost of solar heating systems also reduce the economic attractiveness of these systems in residential buildings. It was found that energy conserving features such as insulation and reduced infiltration had the effect of shortening the effective heating seasons and reducing utilization factor on the solar heating equipment. These measures increased payback periods vis-a-vis conventional alternatives by 25 to 30%. By contract, in larger buildings which are less weather sensitive and which have relatively steady heating and cooling loads, energy conserving design tends to have the opposite effect. It shifts the load toward heating and thus improves solar economics by providing a more balanced and effective utilization of the solar equipment.

VI. APPLICATIONS IN DIFFERENT BUILDINGS

The prospects for successful application of solar cooling were found to be relatively poor in all of the buildings considered. Based on present technology of heat actuated chillers, first cost recovery (payback) periods of greater then fifteen years were required for well insulated single family dwellings and greater than 11 years in larger buildings. In considering solar water and apace heating for the various case study buildings, once again considerations on the utilization factor of solar equipment predominated. The multiple family dwelling was found to be the preferred building application for solar heating. The multiplicity of units and the resulting load diversity results in a higher load factor on the solar equipment than for the single family dwelling.

Generally, the multiple family dwelling offers the shortest payback periods for water heating, ranging from 3-1/2 to 5 years based on the choice between a central system and systems for individual units. Payback periods for space heating plus water heating range from 5-1/2 to 7 years, based on comparing solar hydronic heat pump system costs with the electricity costs for conventional electric heating systems. Larger multiple family dwellings show more attractive economics based on economies of scale in the solar energy system.

In the case of single family dwellings, water heating offers a payback period of ten years, while space heating and water heating offers a payback period of 6 to 8 years compared to electric resistance heating at the 1974 billing rate.

The climate control systems for the large commercial buildings such as the six story office building considered in our study are largely used for cooling. Because the maximum possible economies of scale are achieved in such applications, solar cooling systems with optimally sized storage cone closest to showing attractive economics for these large buildings, i.e. a tan to 15 year payback period can be achieved.

Unfortunately, from the point of view of optimizing the cooling energy supply system, it would be better if the preferred application for solar cooling were s smell building. Since smell buildings are the key factors in the weather sensitive component of a utility load curve, solar cooling for such buildings with appropriate storage would reduce the weather sensitivity and thus improve the load factor.

It was hoped that solar cooling system without thermal energy storage could reduce the demand for electricity during peek demand periods. Figure 5 chows quite clearly why this will typically not be the case. The peek cooling load, and thus the electric system load, continues beyond the period of solar availability into the evening hours. Because of this, the addition of energy storage, i.e. "coolness" storage, in connection with the cooling system greatly enhances the competitive status of the end-use system. Systems for solar heating and cooling and coolness storage in these buildings may afford the flexibility required to reduce the weather sensitivity in the utility load curve to the benefit of the electric system load factor and to the ultimate benefit of the utility customer. However, coolness storage alone appears to be far more cost-effective then solar cooling. This will be discussed further in Section X.

VII. COLLECTOR TECHNOLOGY

COLLECTOR COSTS

The issue of collector cost has long dominated solar economics discussions. We conclude from our analyses that the cost of the solar collectors will probably not dominate the budget for solar heating and water heating systems installed on Southern California homes. If collectors can be produced for $2.77/ft^2 (1974 $) f.o.b. the factory and installed for an additional $2.93/ft^2, then the non-collector costs exceed the collector cost for systems with leas than 1000 ft^2 of area. Detailed cost estimates for non-collector costs based on accepted 1974 data are plotted in Figure 6 and show that non-collector costs increase to ***70%*** of the installed cost for systems as small as 100 ft^2. These 100 ft^2 systems would be adequate to serve an energy conserving single family dwelling in the coastal zone of Southern California and will cost in the neighborhood of $2,000 if collector cost goals are realized.

COLLECTOR DESIGN

A collector with two cover glasses and a selective coating has been found to be economically justified for the water heating and space heating applications if the cost of a durable selective coating is less than .15 $/ft^2 (f.o.b. the manufacturer). For solar augmented heat pump systems an **unglazed** collector is adequate. Collector currently being used for swimming pool heating may be suitable in this application. The evacuated tubular collectors show considerable promise for improving the coat effectiveness of solar cooling applications.

VIII. SOLAR COOLING TECHNOLOGY

The load on the Southern California Edison system reaches its maximum during the summer months. The daily load on the Edison system is typified by the curves in Figure 7. The difference between summer and winter load characteristics is attributable to an increase In demand related to apace cooling in residential and commercial buildings during the summer months. Approximately 25% of the Edison load is weather sensitive. In extreme climatic regions the air conditioning impact is striking. For example, the summertime daily demand peaks in some desert areas can exceed the tinter peaks for these areas often by as much as a factor of three. All prospects for curbing the growth of this summer peak are of great interest to affected electric utilities.

Our careful look at solar cooling technology baaed on various thermodynamic cycles was very discouraging. The moat significant technical barrier to the economic application of solar cooling using thermodynamic cycles is the low coefficient of performance (C.O.P.) of heat actuated chillers. The single stage LiBr absorption machines have a practical C.O.P. of .65, and the organic rankine cycle vapor compression heat pump solar cooling schemes have an overall C.O.P. of under .40 for collector temperature in the range of 200 to 250°F. Since the cost of the thermal energy from the solar collector is roughly competitive with electricity, a C.O.P. for the heat actuated chiller in the range of 1.5 to 3.0 will be needed to make solar cooling economically competitive (from the owner’s point of view) with electricity driven vapor compression machines. Even at *1400°F* a 50 to 200 hp. water rankine cycle expander only has an efficiency of 24% resulting in an effective C.O.P. of .72. Organic rankine cycle prima movers are limited to temperature below 650°F and C. O. P. of leas then .75. Therefore there is little prospect that concentrating collectors with rankine cycle prime movers will compete with conventional air conditioning with economic condition. projected for the next decade. A prototype double effect lithium bromide chiller has been operated with steam at 250°F with a C.O.P. of 1.33. Use of this chiller could reduce solar cooling system payback periods by 30%. However, research is clearly needed on heat actuated chillers with even higher C.O.P. if solar cooling is to compete in the near term with electric vapor compression chillers.

U*-Factor modulation appears to offer an attractive alternative to solar thermodynamic cycle cooling. The technology is conceptually simple. It involves controlling absorption of solar energy and radiation of heat from the building surface. An intuitive interest in this concept has emerged from the discouraging outlook for solar cooling using thermodynamic cycles. However, the economics are not easily established, the application of U-factor modulation integrate traditionally separate disciplines of mechanical engineering and architectural, and the concepts demonstrated to date are radical departures from conventional construction. None the less the idea la only a few years old, and it has been demonstrated to work to stabilize internal temperature. Harold Hay's "Skytherm" house and the "Drum Wall", "Sky Lid", and "Bead Wall" designed by Steve Baer all appear to work. Homes based on these principles, if not these specific designs, would contribute less to the cooling loads on an electric utility. Work is needed to optimize these systems making better use of backup energy sources. Innovation on the basic ideas are needed to make them less architecturally constraining.

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*U . the overall heat transfer coefficient of the building.

IX. SIZING BASED ON ECONOMIC CRITERIA

Solar energy systems should not be sized to carry 100% of the heating load if capital is to be used efficiently. The use of marginal cost analysis for sizing is important if capital Is to be efficiently deployed. The use of average cost for sizing would suggest a broad range where the size of the system makes little difference economically. The marginal cost approach shows the inefficiency of oversizing solar energy systems.

As en example of the marginal cost approach to sizing a solar energy system, consider a solar water heating and space heatlng system for a 2250 ft^2 single family dwelling in the inland valley region. The auxiliary energy saved and the system coat is first calculated as a function of the solar collector size. The marginal coat of solar energy* is then calculated as a function of system size. The results of this analysis are plotted in Figure 8. TWO scales are supplied for capital recovery factors (crf) of 0.2 and 0.1. For example, using the crf = .2 scale a solar energy system should not be installed to produce solar energy unless the (average coat) price of the auxiliary fuel is .045 $/Kwh. If the price of auxiliary fuel is .055 $/Kwh, the marginal cost analysis suggests a collector area of 20 m^2 (215 ft^2). This collector area will supply about 66% of the heating and water heating load of the building used in this example. 66% is typical of the percentage associated with optimal collector sizes for all of our case studies for residential buildings. The proper share is higher in commercial buildings.

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*Marginal Coat = crf x $\frac{\partial(\text{cost})}{\partial(\text{auxiliary energy saved})}$

Where crf = the capital recovery factor.

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X. PROMISING APPROACHES TO SOLAR HEATING SYSTEM DESIGN

As noted earlier, solar space heating systems appear to have the potential of becoming economically attractive from a building owner's present point of view. Use of off-peek-power cooling can improve the economic attractiveness of solar heating when the impact of off-peak power usage on electricity costs is accounted for in the analysis. In the southwest, solar heating systems will only need 100 to 200 ft^2 of collector area in an energy conserving home. In this size range a water storage tank, heat exchanger, and the plumbing needed to transfer solar energy heat to a forced air duct is approximately 1/2 the total cost of the solar heating system. These components can also be used in connection with an electric air conditioner operating at night for off-peak-power cooling. The payback period on the incremental cost of adding a solar heating system to an off-peak power cooling system is thus reduced by a factor of two. Therefore even though solar heating with electric back-up only saves fuel, it comes close to being attractive when coupled with off-peak-power cooling. Solar heat is stored in winter and electrically produced 'coolness" is stored in summer. This combined system can displace both fuel and peak load on the utility.

One solar energy heating system has been identified which is attractive on the basis of fuel caved even without an off-peak-power cooling function. This system is the solar augmented hydronic heat pump in larger apartment and commercial buildings. This system is inexpensive because useful energy can be collected at 700P. The required solar collector need not have any glazing to be affective. The complete solar hydronic heat pump system is illustrated in Figure 9. It may be possible to eliminate the cooling tower in some locations where nocturnal radiation is adequate to handle the cooling load.

solar system was assumed to be a commodity substitution investment decision. The investment analysis involves calculation of the rate of return on the investment in a solar energy system from saving electricity or natural gas. As conventional fuel prices increase compared to the cost of solar energy systems, solar energy systems because more competitive with electricity and natural gas. Once the return on investment reaches a minimum acceptable level, solar energy systems begin to penetrate the market.

The minimum acceptable rate of return was assumed to be different for different building Industry submarkets reflecting the relative conservatism of respective submarkets. For example, the commercial submarket was assumed to have rate return requirement equal to the cost of money (8-12%) whereas the single family submarket required rates of return equal to 18-20% reflecting the higher first-cost sensitivity of the single family submarket (see Figure 10). These assumptions were identical to requiring a 5 to 5-1/2 year payback before solar energy systems would be used in the single family submarket and 8-10 years before use in the commercial market.*

Penetration rates for the new and retrofit markets ware chosen to reflect the historical resistance of the building industry to innovation. Historical statistics on the penetration rates of mobile homes, heat pumps, central air conditioners, and others were considered in selecting penetration rates for solar energy systems.

Energy Scenarios

The second set of factors influencing market penetration are the future prices and availability of natural gas and electricity. One of the

*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.

most difficult problem in trying to assess the impact of solar energy in the next twenty-five 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 buildings comrise about 10-15% of the new market as of 1974). The price of electricity rises from the current $.035 per Kwh at a 4% annual rate above inflation (that is, a 4% growth rate in constant 1974 dollars); gas prices rise at the rate of inflation in this scenario. This scenario will produce the highest solar energy penetration since solar competes beet with electricity, and this scenario postulates running out of natural gas for new hookups end 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 price of natural gee is postulated to double by 1978 end thereafter 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.

*1974 Dollars

The third scenario, the "retarded energy growth" scenario postulates a constant residential electricity price at $0.035 per Kwh (in 1974 dollars)* until 1985, after which time the price declines in real terms slowly (-.33% per year). After doubling at 1978, natural gas price remains constant (in real terms) through 2000 according to this scenario.

A summary of these three scenarios is given in Figure 11. 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. Each energy scenario assumes that all buildings built after 1975 will be energy conserving (have additional Insulation in the walls end reduced infiltration).

Solar Energy System Coat

The third major factor which affects the impact of solar energy concerns the assumed cost of solar energy component and system. The primary analysis of impact was performed assuming a solar collector cost of $2.77 f.o.b. the factory. This la 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 installation 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).

Financial Incentives

The analysis included the possibility of financial incentives which reduce the effective first-cost of solar energy systems. The incentives

*Prices for other rate classes are assumed to vary in proportion to residential prices.

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 coat of the solar energy system. From our analysis of proposed and pending legislation at the Federal level, some form of incentive appears to be likely. (For example, HR5860,which provides a 25% incentive to residential users of solar energy,has passed the House and is in conference). The impacts of solar energy were studied using three different incentive levels; 1) no incentive, 2) 25% incentive and a 50% incentive.

The Single Family Market

Scenarios for the future solar energy share (percentage) of the total energy used for heating and cooling and water heating by single family homes are tabulated in figure 12. The percentage in figure 12 are the aggregation of all estimated adoptions in both the new and retrofit markets in each of the three most significant microclimatic zones of the Southern California Edison Company service territory.

The buyer decision criterion stated as a required payback period before he will buy is related to the level of incentive. For example, if a buyer requires 5 year payback period with a 25% first cost reducing incentive, this is identical in economic terms, to requiring a longer payback period of 7 years with no incentive. Using this relationship it is possible to examine the energy savings from the use of solar energy considering different decision criteria and incentives as well as under different energy scenarios.

The gas curtailment scenario produces the greatest penetration of solar energy systems. If potential buyers are willing to accept a 5 year payback and receive no first cost incentive, then solar energy displaces 10% of the projected electrical energy needed for heating, cooling and water heating in the year 2000. If, however, potential buyers are willing to accept a 7 year payback with no first cost incentive (or equivalently a 5½ year payback made possible by a 25% incentive) then solar energy displaces 25% in the year 2000. Similarly, if potential buyers are willing to accept an 11 year payback with no first coat incentive (or equivalently a 5½ year payback made possible by a 50% incentive) solar energy displaces 36% of the projected electrical energy for apace and water heating and cooling in the year 2000 under the gas curtailment scenario.

As can be seen from Figure 12, no penetration occurs prior to the year 2000 under the other scenarios unless potential buyers will accept 11 year paybacks (or require 5½ 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.

Impact of Incentive

Another way of presenting these results for scenario 1 is given in Figure 13 which shows the energy displaced by solar systems on single family dwellings from 1975 to the year 2000. The lower curve in figure 13 is the growth of energy displaced by solar energy assuming no incentive and a 5½ year payback requirement before potential users buy solar systems. The middle 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. The upper curve in Figure 13 is the total energy used. The other dashed curves represent 50%, 10% and 1% of the total energy use.

These dashed curves provide a means for evaluating the impact of incentive. upon the use of solar energy. Examining the dashed curve called 10% of total energy use, it is apparent that there is a significant time difference between the times at which solar energy displaces this amount of energy at each of the incentive levels. The difference between the time at which crossover for no incentive and 25% incentive curves occurs is about 7 - 9 year., which indicates that a 25% incentive till speed the adoption of a given level of solar energy use by about 7 - 9 years. Similarly by examining the time of crossover for 25% and 50% incentive curves, the difference between a 25% and a 50% incentive can be seen to be 5 - 7 years.

Comparison between Microclimatic Regions

The market penetration of solar energy systems in each microclimatic zone for single family buildings was performed to determine difference between zones. The resulting energy displaced in the year 2000 in the gas curtailment scenerio is given in Figure 14. The results show that solar energy will achieve the highest percentage 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 cause this result. First the temperate climate at the beach causes solar space heating equipment to have a 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 doesn't penetrate the inland and high desert markets until after 1990, the percentage of total HVAC energy displaced by solar is less in these regions.

Office Buildings

The potential of solar energy was also examined for office buildings. Figure 15 presents the energy displaced for office buildings as a function of time for the gas curtailment scenario. As can be seen from this figure market penetration of solar energy reaches a minimum of 10% in the year 2000. The lower penetration in office buildings compared to single family buildings is due to the relatively larger cooling requirement for offices. Because near term technology for solar cooling is not expected to be as economical as heating for single folly buildings, the percent penetration in office buildings is expected to be lower even though the adoption criteria are leas severe.

XII. SUMMARY OF FINDINGS

The use of solar energy for apace heating, water heating and cooling has been investigated in the residential and commercial markets of Southern California. Important conclusions have been reached concerning: the design and application of systems; the best submarkets; the growth of solar energy usage in buildings.

Five microclimatic zones have been defined in Southern California Edison's service territory. While the size of solar heating systems varies by a factor of three between these zones, the payback periods vary by less than l0%. The coastal zone has the lowest heating load and the shortest payback period for a solar heating system. Solar water heating and solar cooling systems look better in the high desert region than along the coast.

Larger buildings are more attractive for solar energy systems because of economies of scale, and this is one reason why multiple family dwelling applications are more economically attractive than single family applications. A solar water heater with a 36 ft.^{2} collector is estimated to cost over $850 ($23/ft.^{2})*. A solar apace heating and water heating system with 200 ft.^{2} of collector for a large single family home is estimated to cost $3000 ($15/ft.^{2}),* while a solar water heater for a multiple family building which requires a 1000 ft.^{2} collector is estimated to coat $8000 ($8/ft.^{2}).* A system with 12,800 ft.^{2} of collector to heat and cool a 50,000 ft.^{2} office the coat is estimated to be $100,000 (under $8/ft.^{2}).*

The shortest payback periods have been found in the multiple family and commercial markets. Solar water heating can have a payback period as

*Eventual mass production cost in 1974 dollars.

short as 3½ years vs. electric water heating at the 1974 billing rate. The solar augmented hydronic heat pump for space heating in multifamily dwellings is estimated to have a 3½ year payback. These systems can be economically justified on the basis of the fuel savings by the utility company. Combined water heating and space heating systems have a 5½ year payback period.

In the single family market, combined solar water heating and space heating systems are projected to have a payback period in the range of 6-8 years compared to electric resistance heating. Longer payback periods are estimated for the solar augmented heat pump; however the accuracy of this estimate is much poorer. A payback period of 5½ years is felt to be needed to make a system attractive to the single family market.

Solar cooling can be used to reduce utility peak loads. However, the payback periods for solar cooling compared to electric vapor compression cooling are extremely long except when combined with solar heating systems. Even when combined with solar heating systems the payback period is optimistically estimated to be greater than 11 years in all applications. The major technical barrier to solar cooling is the low C.O.P. of the thermodynamic cycles currently being investigated.

An off-peak-power cooling system combined with solar space heating provides a technically attractive option for reducing peak load in both the residential and commercial markets. The off-peak-power cooling systems justify the cost of an on-site thermal energy storage tank. Since the tank can also be used to store solar energy for heating, the incremental cost for adding a solar heating system is reduced. While solar heating using electric auxiliary only displaces fuel, the combined system displaces both fuel and capacity.

All of the solar HVAC system concepts Investigated require auxiliary energy if capital is to be deployed efficiently: Solar cooling systems which carry over 50% of the cooling energy load only reduce the peak demand on the auxiliary electrical system by less than 25%. The peak auxiliary demand occurs on days which are hot and cloudy, whereas current Edison maximum peak loads occur on hot, sunny days. In the case of solar space and water heating systems, electrical energy may be needed every day for extended periods in the cooler months. A utility with a summer peak could supply this energy directly and via heat pumps and thus improve its system load factor.

Significant market penetration of solar water and apace heating in the multiple family and commercial markets only requires the development of markets adequate to justify mass production tooling for currently understood technology. In the single family market significant penetration can occur if: 1) mass production prices are achieved, and 2) new hook-ups of natural gas are curtailed and electric rates tend to escalate faster than Inflation, alternatively If: l)consumers are willing to accept an n-year payback on the solar equipment, or 2) incentive are provided at a level equivalent to a 50% first coat reduction.

Of perhaps greatest significance, we have found that there are ways of combining heating and cooling concepts such that use of solar energy and electrical energy is more economical for the utility and its customers than use of either alone. This suggests an optimistic view toward the near-and long-term prospects for commercial utilization of solar energy in buildings. It is with this view that the Southern California Edison Company will continue to support development of such attractive systems.

XIII. REFERENCES

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2. Schoen, Richard, Jerome Weingart and Alan S. Hirshberg, New Energy Technologies for Buildings: Institutional Problems and solutions, Ballinger Publishing Co., Cambridge, Mass., 1975.

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Figure 1.

SOUTHERN CALIFORNIA EDISON COMPANY SERVICE TERRITORY

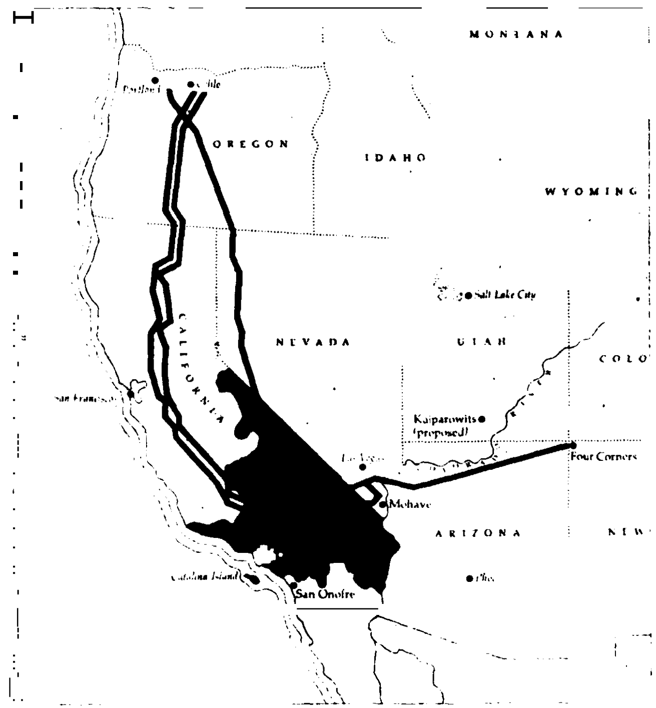

Figure 2.

SOUTHERN CALIFORNIA WEATHER ZONES

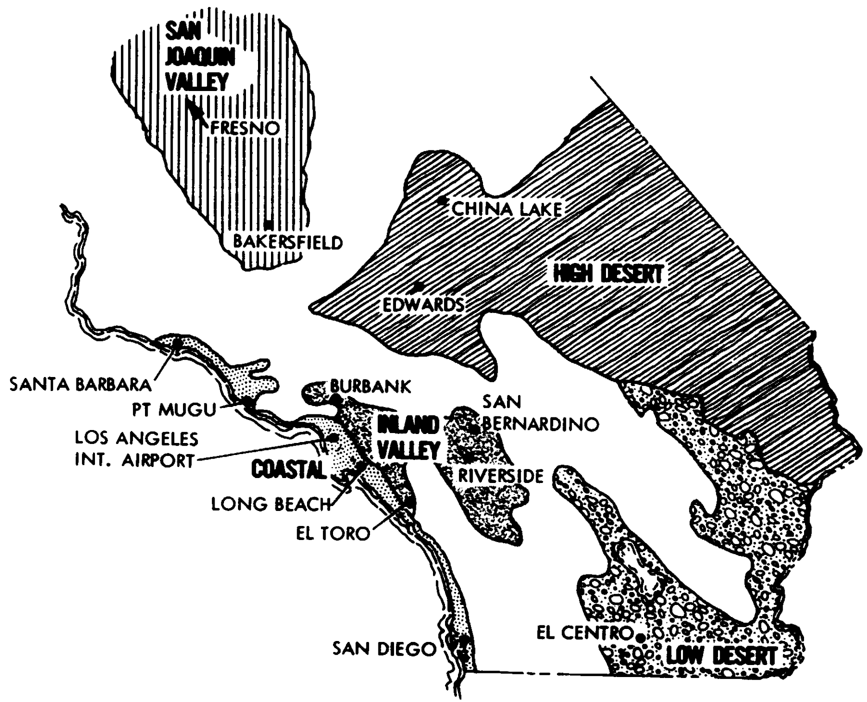

Figure 3.

SOLAR HEATING AND COOLING CASE STUDIES

SYSTEMS	BUILDINGS: 2250 ft² SINGLE FAMILY DWELLING	9 UNIT MULTIPLE FAMILY DWELLING	6 STORY 50,000ft² OFFICE	3 STORY 145,000 ft² DEPT STORE
WATER HEATING	• PUMPED	• CENTRAL AUX • IND AUX		
WH + SPACE HEATING	• HYDRONIC	• HYDRONIC		
SOLAR AUGMENTED HEAT PUMP	• RESISTANCE AUXILIARY	• DISTRIBUTED HYDRONIC	• DISTRIBUTED HYDRONIC	
WH + SH + AIR CONDITIONING	• HYDRONIC • ABSORPTION CHILLER	• HYDRONIC • ABSORPTION CHILLER	• HYDRONIC • ABSORPTION CHILLER	• HYDRONIC • ABSORPTION CHILLER

Figure 4.

SOLAR HYDRONIC HEAT PUMP

- 9-UNIT MULTIPLE FAM LY DWELLING
- SOLAR SHARE = 75%
- ELECTRIC AUXILIARY
- COLLECTOR- 49° TILT 80°F

	COLLECTOR AREA, ft^2		SOLAR ENERGY COST, $/kWh	
	STANDARD BUILDING	ENERGY CONSERVING	STANDARD BUILDING	ENERGY CONSERVING
COAST	320	220	0.032	0.041
INLAND	430	270	0.031	0.042
HIGH DESERT	1100	750	0.030	0.036

Figure 5.

SOLAR COOLING ELECTRICAL LOAD PROFILE

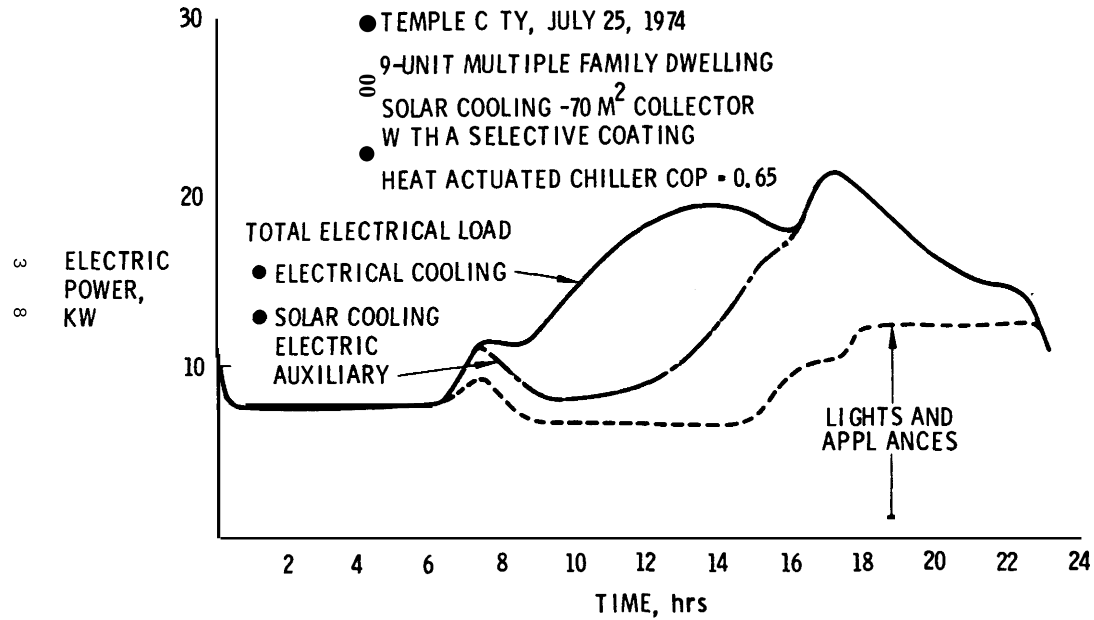

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Figure 6.

COST OF SOLAR HYDRONIC WATER HEATING + SPACE HEATING

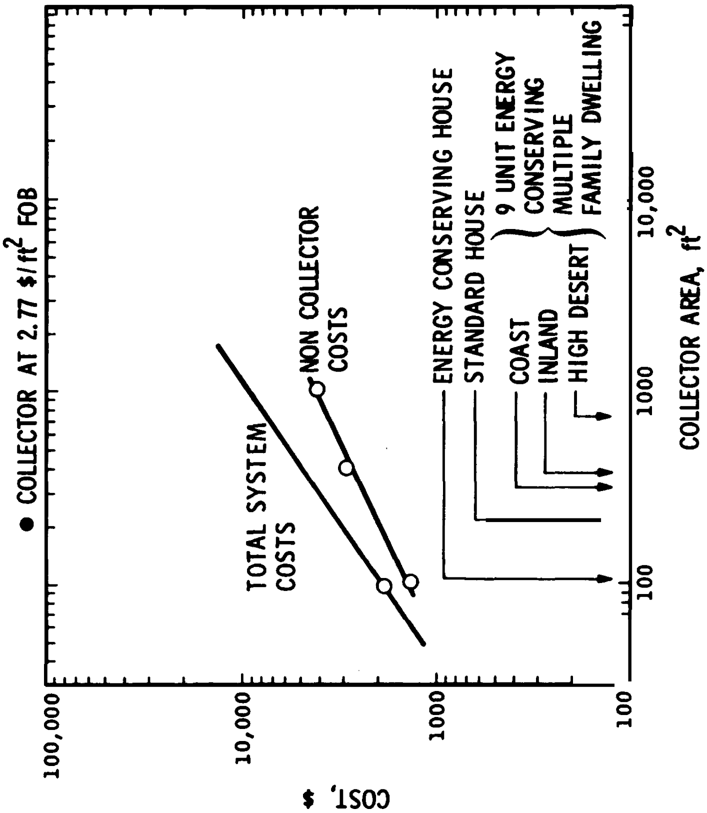
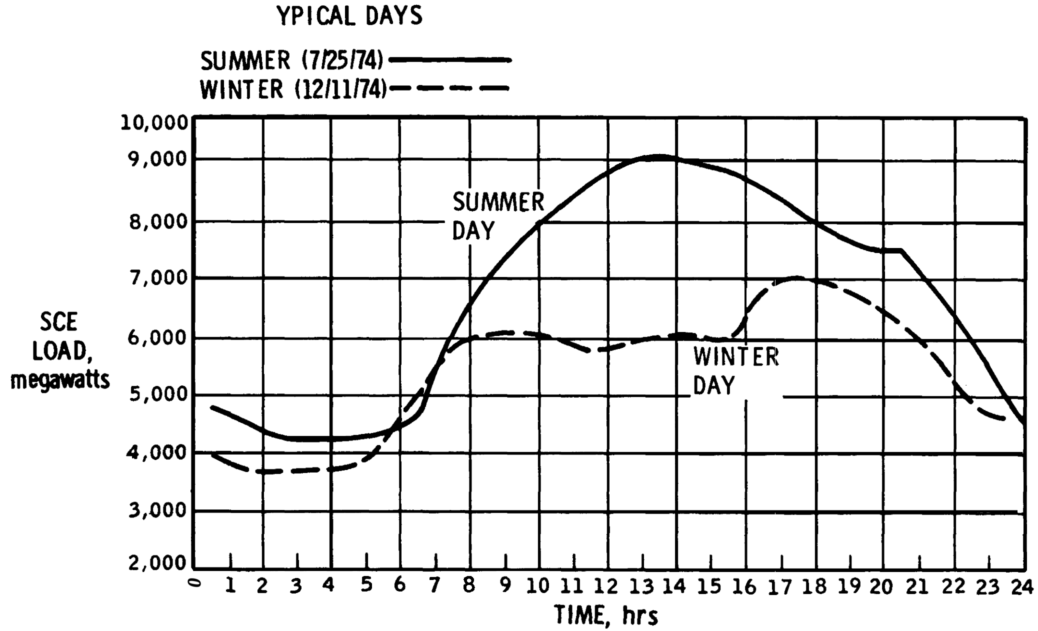


Figure 7.

SCE LOAD PROFILE



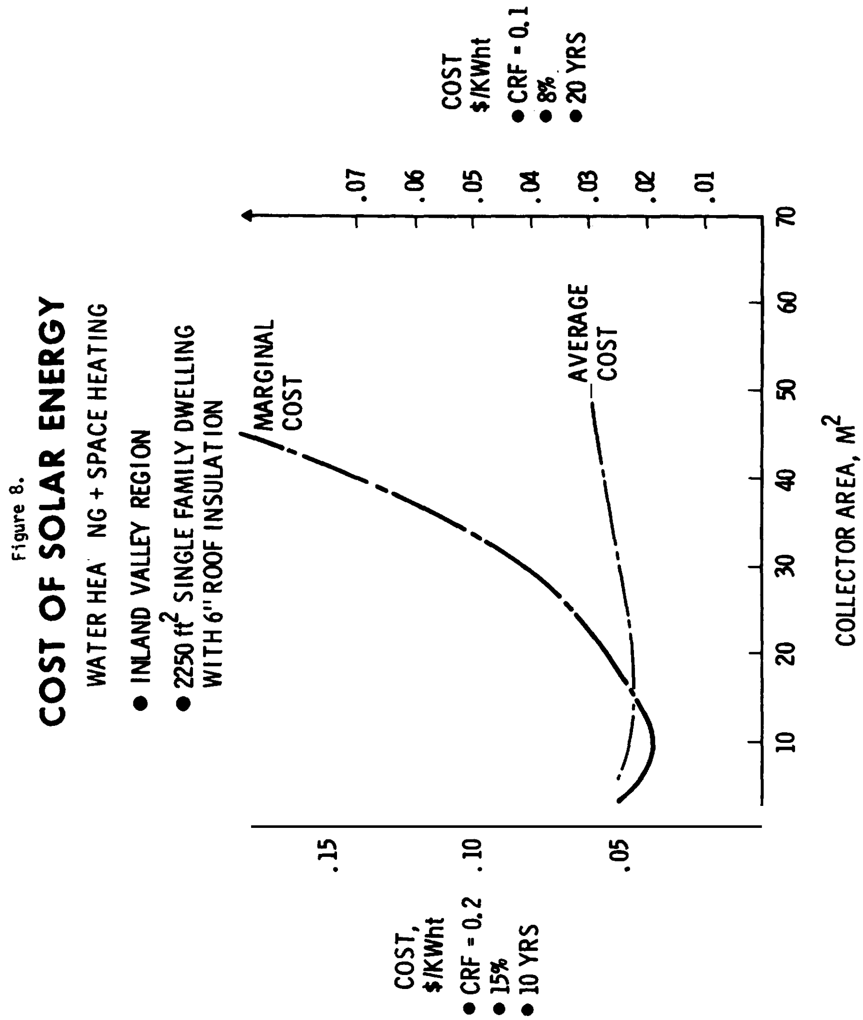
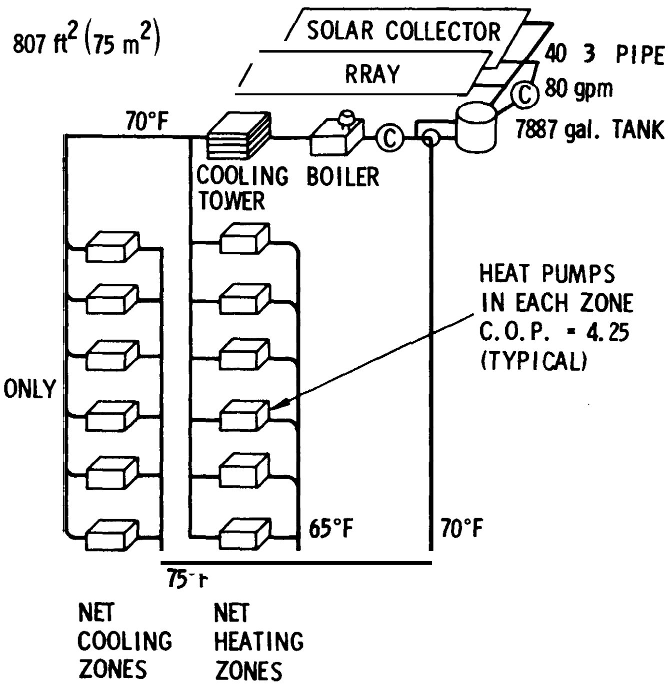


Figure 8.
COST OF SOLAR ENERGY

Figure 9.

SOLAR ×YDRONIC HEAT PUMP



- ENERGY CONSERV NG OFF CE
- INLAND ZONE (BURBANK)
- TEMPERATURES ILLUSTRATIVE ONLY

Figure 10.

RETURN ON INVESTMENT

$$\text{ANNUAL SAVINGS} = \text{INCENTIVE) (FIRST COST)} \quad \text{RO} \frac{(1 + \text{ROI})^{\text{LIFE}}}{(1 + \text{ROI})^{\text{LIFE}}{}_{-1}}$$

MINIMUM REQUIRED

VARIES WITH USER

	NEW	RETROFIT
HOME-OWNER	18%	20%
APT. OWNER	15%	18%
COMMERCIAL OWNER	8%	12%

Figure 11.

SCENARIOS FOR MARKET PENETRATION

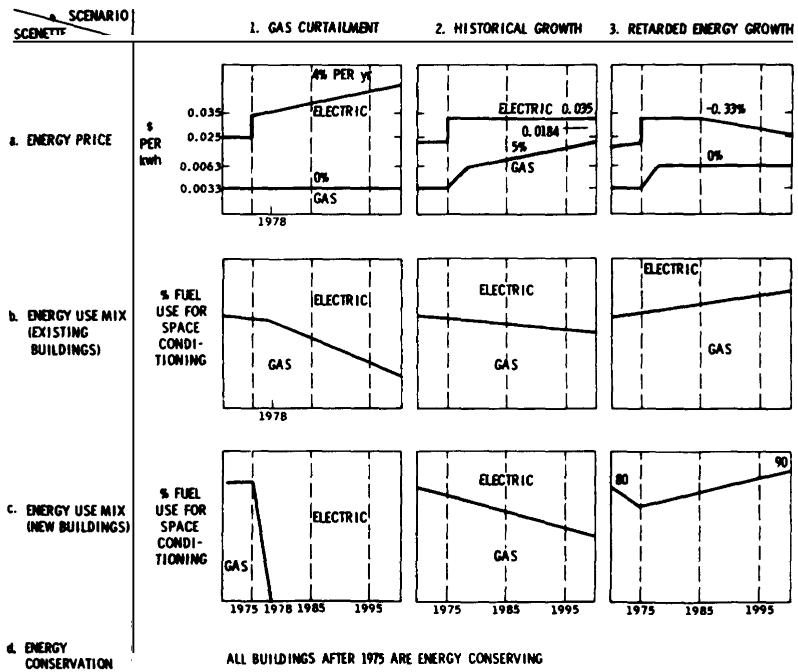


Figure 12. Solar Energy Savings *Scenarios* in the Single Family Market.

Adoption Criteria and Incentive Level		Solar Energy Savings, percentage		
Payback Period, yrs.		5-1/2	5-1/2	5-1/2
Incentive		0	25	50%
or			- or -	- or -
Payback Period			7	I1
Incentive			0	0
Gas Curtailment Scenario	Y 1980	0.0	0.0	3.3
	E 1985	0.0	2.1	11.2
	A 1990	0.7	7.0	20.8
	R 1995	3.7	15.7	29.4
	2000	10.2	25.2	36.1
Historical Growth Scenario	Y 1980	0.0	0.0	0.5
	E 1985	0.0	0.0	1.9
	A 1990	0.0	0.0	4.4
	R 1995	0.0	0.0	7.8
	2000	0.0	0.0	12.1
Retarded Energy Growth Scenario	Y 1980	0.0	0.0	0.4
	E 1985	0.0	0.0	1.3
	A 1990	0.0	0.0	2.6
	R 1995	0.0	0.0	4.0
	2000	0.0	0.0	5.5

*New and retrofit installations are accounted for. Payback periods refer to new installations. Retrofit payback periods are about 10% less.

Figure 13.

ENERGY DISPLACED BY SOLAR SYSTEMS

GAS CURTAILMENT, SCENARIO, ALL ZONES, SINGLE FAMILY

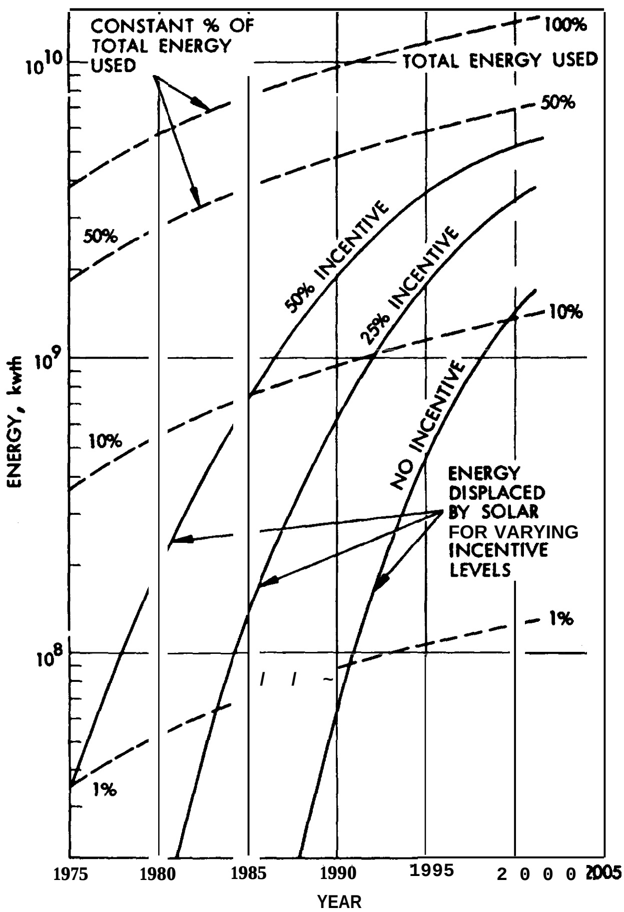


Figure 14.

MARKET PENETRATION FOR SINGLE FAMILY

SCENARIO 1, EACH ZONE, YEAR 2000
(PERCENT PENETRATION)

	NO INCENTIVE	25% INCENTIVE	50% INCENTIVE
BEACH 2530 x 10^6* kwh	14	32	44
INLAND 8400 x 10^6 kwh	8	23	34
HIGH DESERT 2140 X 10^6 kwh	13	24	30
ALL ZONES 13880 x 10^6 kwh	10	25	36

* TOTAL ELECTRICAL ENERGY FOR HEATING. COOLING AND WATER HEATING IF SOLAR ENERGY IS NOT USED

Figure 15.

ENERGY DISPLACED BY SOLAR ENERGY SYSTEMS IN OFFICE BUILDINGS

SCENARIO 1, ALL ZONES