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EQL
Memorandum
No. 11

PROJECT SAGE PHASE I REPORT

SOLAR ASSISTED GAS ENERGY WATER HEATING FEASIBILITY FOR APPLICATION IN NEW APARTMENTS

by Edgar S. Davis

ENVIRONMENTAL QUALITY LABORATORY

Principally supported by the Southern California Gas Company
Supported in part by the National Science Foundation Research Applied to National Needs, (RANN), under Grant No. GI-29726

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The Study Team

Edgar S. Davis of the Jet Propulsion Laboratory was the leader of the study team. Members of the team contributing to this report included: R. Caputo, J. Fuhrman, A.S. Hirshberg, H.N. Riise, G. Spivak and B. Zeldin, all from the Jet Propulsion Laboratory, and Richard Schoen from the UCLA School of Architecture.

ACKNOWLEDGEMENTS

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In addition, we would like to recognize the cooperation and support received from several outside sources: Al Ottum of Raypak, Inc., designer of the hot water heating system used on the study building; Ed Lownes, builder/developer of the building used in the study; L.Z. Brown, Inc., which supplied detailed and authoritative cost estimates for installation of the solar water heating system in the study building.

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Although solar water heating for Southern California apartments was chosen because of its significance to energy conservation, it is attractive for many other reasons. The most significant of these is that of all the applications for solar energy, multiple-unit water heating appears to have the best chance of becoming economically competitive. (See Ref. 2)

In this study, three objectives were accomplished:

1. Definition of a baseline system, specifying plumbing configuration, materials, components, and collector design concept.
2. Estimation of system cost and performance.
3. Identification of alternate approaches to the system and component design, enabling solar water heating to become commercially viable.

After briefly examining a wide variety of system configurations for a gas-supplemented solar water heater, we chose one system for a preliminary design study. This "baseline system" could be built completely with existing technology. Technical performance of the baseline system was evaluated by a computer simulation model, using hourly weather data for the year 1961 obtained from the weather station in Burbank, California. Solar radiation at Burbank is typical of a large region of the Los Angeles Basin. Average hourly hot water demand for apartments from Reference 1 was used for the simulation of demand.

In order to estimate the cost of installing this system in an apartment, we chose a recently completed apartment in Pasadena for a detailed study of the problems involved in designing a system for an actual installation.

The study building has 3 stories and contains 32 apartment units, a recreation room, and subterranean parking. Living density of the total complex is 40 units per acre. This building is typical of apartment dwellings currently under construction in Pasadena and other high land-value areas in the Los Angeles Basin. A sketch of the study building is shown in Figure 1-2.

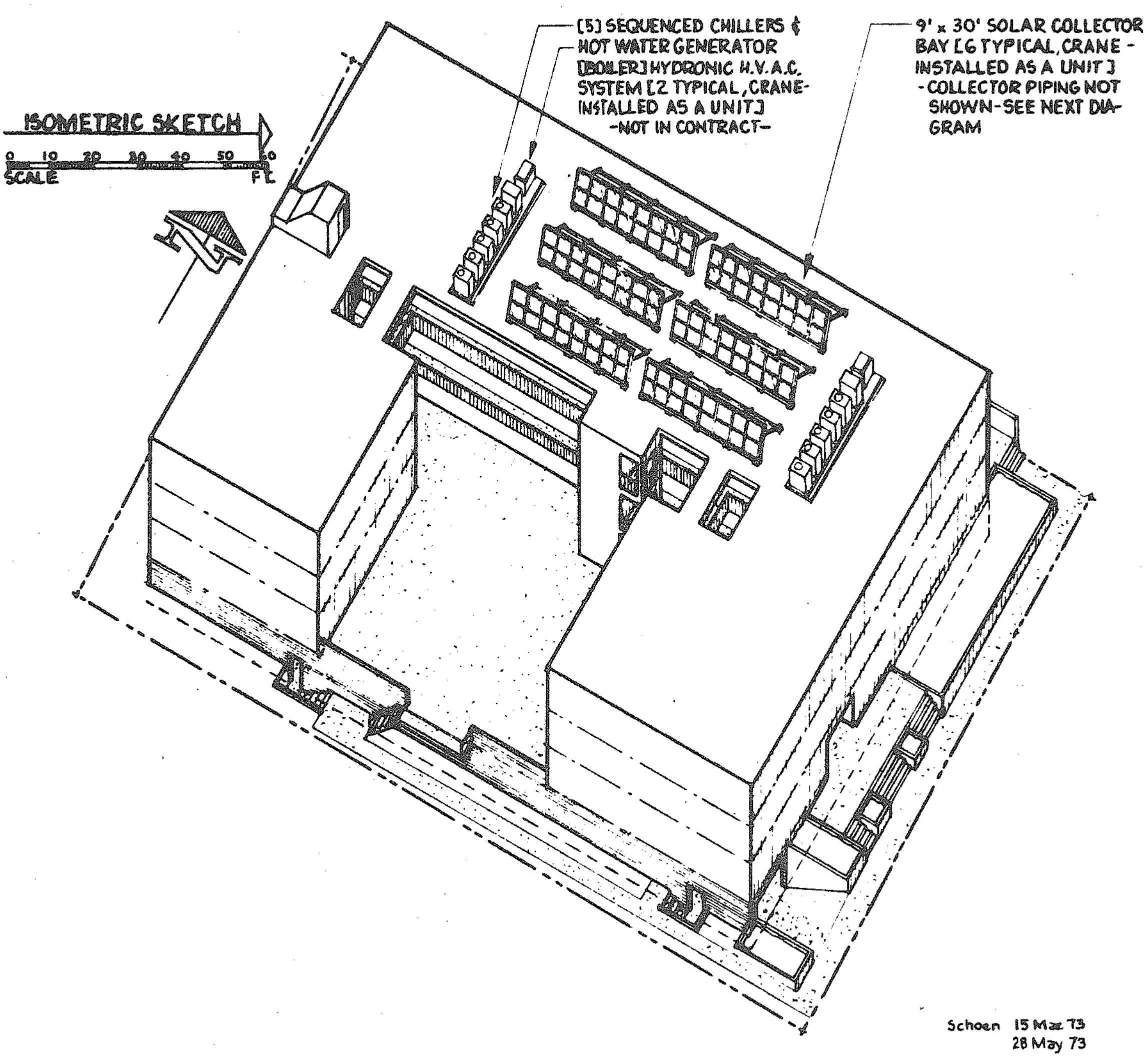
Figure 1-2

BASELINE DESIGN STUDY BLDG. • PROJECT SAGE

EL MOLINO CONDOMINIUM APARTMENTS PASADENA, CALIF.

497 SO. EL MOLINO AVE. [UNDER CONSTRUCTION]

HAUGAARD: ELROD ASSOC.- ARCHITECTS ED LOWNES, BUILDER



The study building has a Raypak gas hydronic hot water and space heating system. In this system, two 750,000 BTU/hr gas boilers heat water circulating through the building to 140°F. Fan coil units in each apartment extract energy for space heating according to the needs of the individual apartment. Domestic hot water is taken directly from the circulating line at each apartment. In principle, solar energy could also be used to supply energy for space heating in such a combined hot water and space heating system. However, design of a system to meet both space and water heating needs was beyond the scope of this study.

The solar collector for the baseline system is shown to scale on the study building in Figure 1-2. Since we knew that the solar collector assembly would be expensive, various cost-reducing concepts for designing and manufacturing a solar collector were examined.

The purpose of this memorandum is to summarize the principal conclusions reached concerning the technical feasibility and relative economic position of the use of solar water heating for new apartments. The depth of technical detail is limited to that needed to support the conclusions presented.

SECTION II

SOLAR WATER HEATING SYSTEMS

There are many configurations for a gas-supplemented solar water heating system, all of which have three principal components: (1) a solar collector, (2) an energy storage component, and (3) a supplemental gas boiler. In addition, several configurations that were examined used a heat exchanger to isolate some of the components from the domestic water supply.

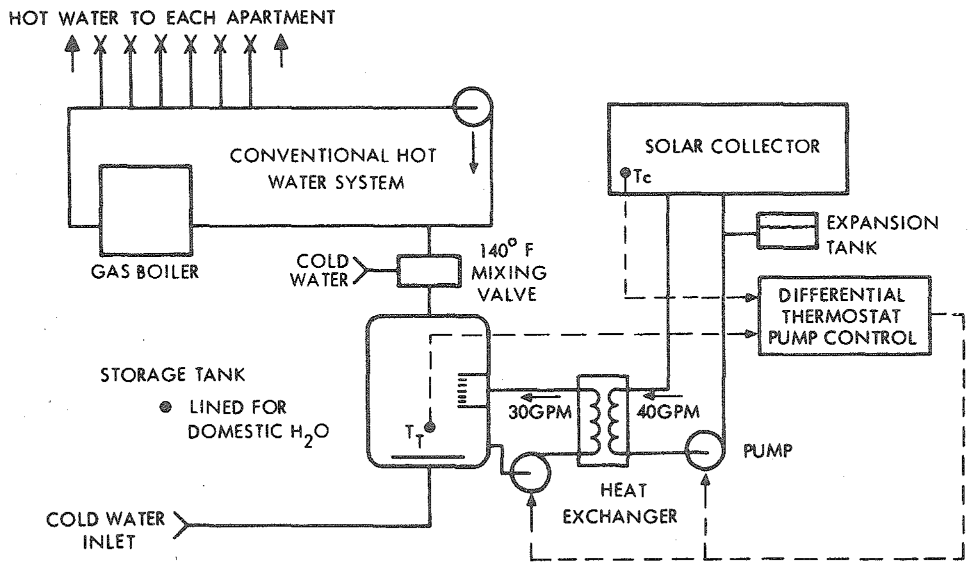
A. THE BASELINE SYSTEM

The baseline system (S1), shown in Figure 2-1, was chosen for two principal reasons: (1) the performance of this system is predictable; (2) the two-fluid design permitted exploration of low-cost options for the collector absorber plate because of isolation from the high pressure, corrosion, and scaling of the domestic water supply. The baseline system was initially judged to have a higher cost than alternate systems because the storage tank in the baseline system is required to store domestic water at the pressure of the supply main. However, the baseline system establishes a solid point of reference for future research and development.

Components of the baseline system are sized to minimize the cost of hot water in a 32-unit apartment. In the Baseline System solar energy is collected by a fixed-orientation, flat plate collector with an area of 1400 ft^2 (or 43 ft^2 per unit). Water containing corrosion inhibitors is circulated between the collector and the heat exchanger at a rate of 40 gallons per minute by a fractional horsepower pump. In the heat exchanger thermal energy is transferred to the domestic water which is stored in a 1200-gallon tank (37.5 gallons per unit). A second pump is used to connect the heat exchanger to the tank. The temperature difference across the heat exchanger is approximately 18°F. On a clear day, enough energy is added to the tank to raise it to an average temperature of 137°F. (Although density stratification would occur in the tank and the temperature at the top would exceed the average, we have not yet included this phenomenon in our analysis.) A complete specification of parameters for the baseline system is given in Appendix A.

Figure 2-1

SOLAR ASSISTED GAS ENERGY WATER HEATER
SYSTEM S1
THE BASELINE SYSTEM



As hot water is consumed by the occupants of the apartments, water at the temperature of the tank is delivered to the circulation loop. Since this water is already heated, use of the gas boiler is minimized. Other researchers have shown that by placing the gas boiler in series with the solar preheater system, fuel consumption is effectively reduced. (See Ref. 3.)

It is important to point out that the baseline system does not provide any energy to the fraction of the energy load lost in the circulation line. We estimate that the circulation line loss for a well-insulated system accounts for 20 percent of the total energy demand for water heating (see Table 2-1). Although the baseline system cannot supply energy to the circulation line loss, there are minor variations of the baseline system which can.

Table 2-1. Central Gas Water Heating System Energy Budget

	Annual Energy per Apartment Unit	
	Energy Supplied	Gas Energy Required*
Hot water — (58 gal/day/unit** 80°F Rise)	14.1	17.6
Circulation Line Loss*** (12.5 BTU/hr/ft)	3.5	4.4
Total	17.6	22.0 x 10^6 BTU/yr/unit

*80% Gas boiler efficiency assumed to be 80%.

**Reference 1

***Calculated for a 32-unit apartment dwelling using insulation representing good conventional practice. Poor practice could result in a loss of 19 BTU/hr/ft, while use of foil covered ISOFOAM insulation could reduce the loss to 8 BTU/hr/ft.

Basic control of solar energy collection involves sensing the temperature near the bottom of the tank and at the outlet of the collector. Fluid is circulated through the collector, and energy is stored in the tank whenever the collector output temperature exceeds the minimum tank temperature by a pre-set temperature difference. This pre-set temperature difference is established to limit oscillation of the flow at transitions from solar-collecting to nonsolar-collecting modes. Differential thermostats which can perform the required temperature-sensing and switch-closing functions are commercially available. One suitable device is the L443B (Minneapolis Honeywell).

B. ALTERNATE SYSTEMS

1. System S2. System S2 (Figure 2-2) was initially assessed as the best prospect for being the lowest cost system. The principal differences between System S2 and the baseline system are the location of the heater exchanger and the use of a low-pressure tank for storing solar energy. The collector required for this system would be identical to that of the baseline system.

System S2 can supply energy to the circulation line loss. For the same system sizing as the baseline system, the storage tank in System S2 would achieve a temperature of 137 + 18 = 155°F, thus making supply of energy to the circulation line thermodynamically possible.

Although System S2 appeared to be the lowest cost system, we did not have adequate resources and data in this initial phase of the study to analyze the performance of the heat exchanger under transient flow conditions inherent in the system.

2. System S3. System S3 (Figure 2-3) is a single-fluid system which circulates the domestic water through the collector. Since system efficiency is improved by elimination of the heat exchanger, the collector area for a cost-optimized system is reduced to approximately 1200 ft^2. However, the cost of the collector per unit area is increased by the requirement to handle domestic water at the pressure of the supply main. The net result is a system with approximately the same cost as that of the baseline system, but with a potentially serious collector maintenance problem if used with hard water.

Figure 2-2

SOLAR ASSISTED GAS ENERGY WATER HEATER SYSTEM S2

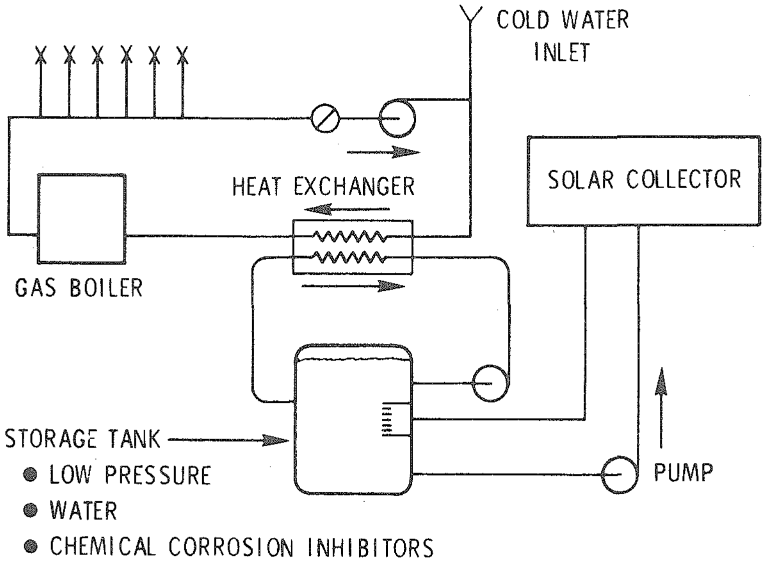
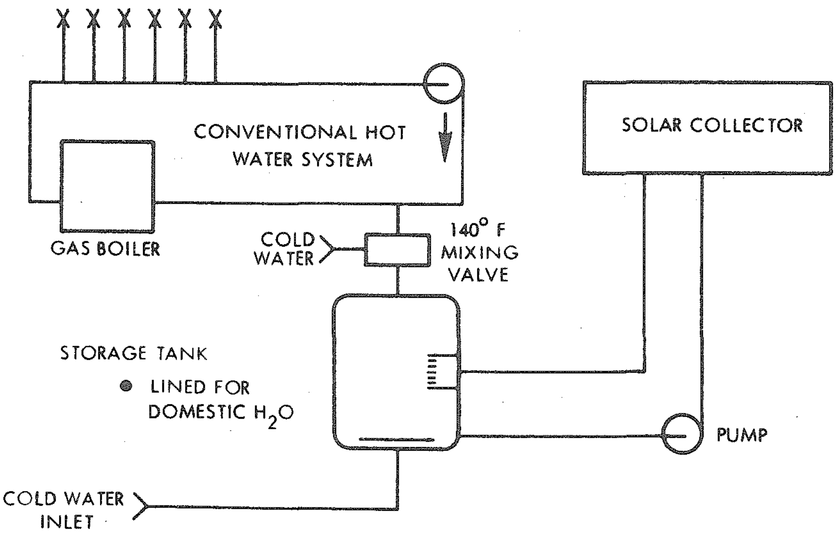


Figure 2-3

SOLAR ASSISTED GAS ENERGY WATER HEATER SYSTEM S3 A ONE-FLUID SYSTEM

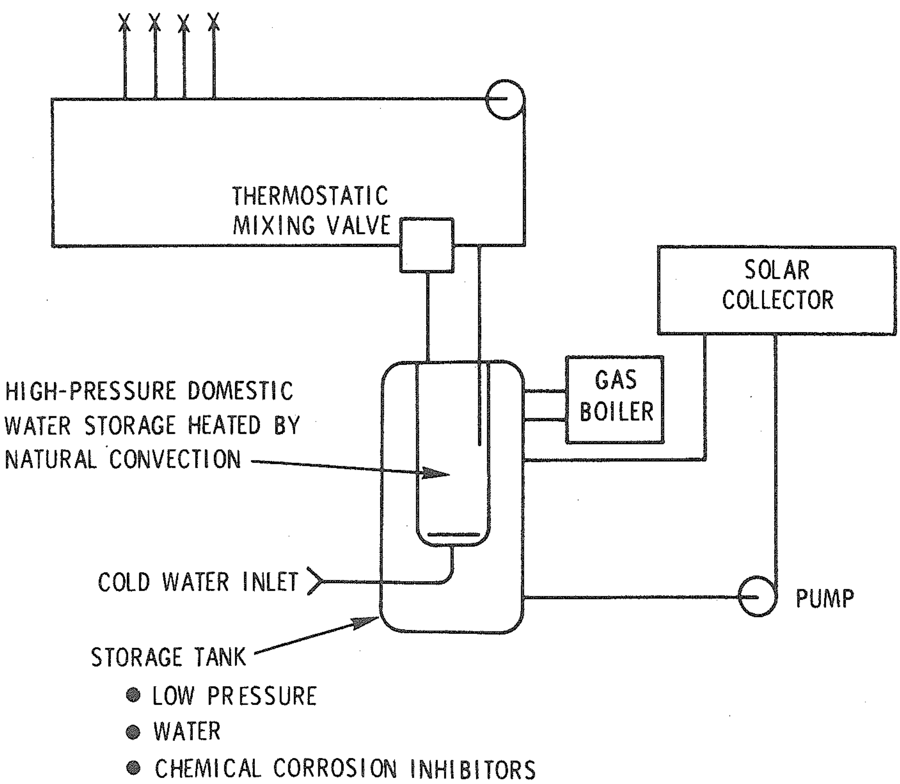


3. <u>System S4</u>. Since the concept for System S4 (Figure 2-4) was introduced in the middle of the first phase of the project, it did not receive much design and analysis evaluation. It is, however, included here because it has the potential of being the lowest cost system meeting the requirements for apartment unit application. Heat exchanger and thermal storage functions are combined in the main storage tank.

The gas boiler is moved from the circulation line to the storage tank, where it can be reduced in size and complexity. Solar energy is supplied to circulation line loss whenever solar energy heats the top of the tank to a temperature exceeding the control temperature of the gas boiler.

Figure 2-4

SOLAR ASSISTED GAS ENERGY WATER HEATER SYSTEM S4



SECTION III

SYSTEM SIZING AND TECHNICAL PERFORMANCE

With a system sized to minimize the cost of hot water, solar energy can supply a significant share of the water heating energy load. The auxiliary energy needed to satisfy the remainder of the water heating load can be conveniently supplied by a gas utility.

The collector and tank for the baseline solar water heating system are sized to minimize the "total annualized cost" of supplying hot water to the 32-unit study apartment. In minimizing the total annualized cost of hot water, capital investment in solar energy equipment is balanced by reduced fuel cost over the life of the system. In Figure 3-1, the annualized cost* of the baseline system is compared to the annualized cost of all-gas water heating as a function of gas price and baseline system collector area. At a gas value of $4.50/$10^6$ BTUs, the minimum cost of the solar-assisted system is less than the cost of the all-gas system. The collector area for minimum cost is 1400 ft^2. The optimum tank volume has been determined in a similar manner.

Using the total annualized cost as a design criterion does not maximize the amount of energy conserved. However, it is the most likely criterion to be used for solar energy systems. Figure 3-2 shows how the share of the water heating load increases in proportion to the increase in the collector area. The baseline system is sized to supply approximately 80 percent of the water heating load

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* See Section VI for the rationale for economic parameters.

on a sunny day in June. Our analysis shows that the system can be expected to supply approximately 67 percent of the annual water heating load.

Figure 3-1

SOLAR COLLECTOR SIZING STUDY

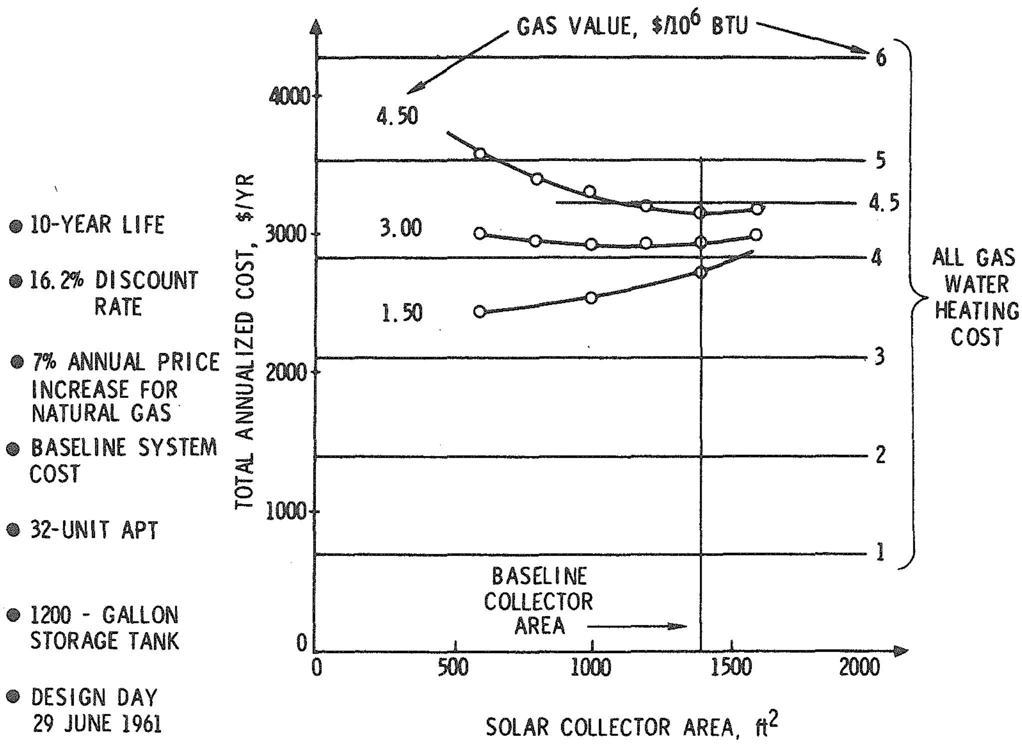
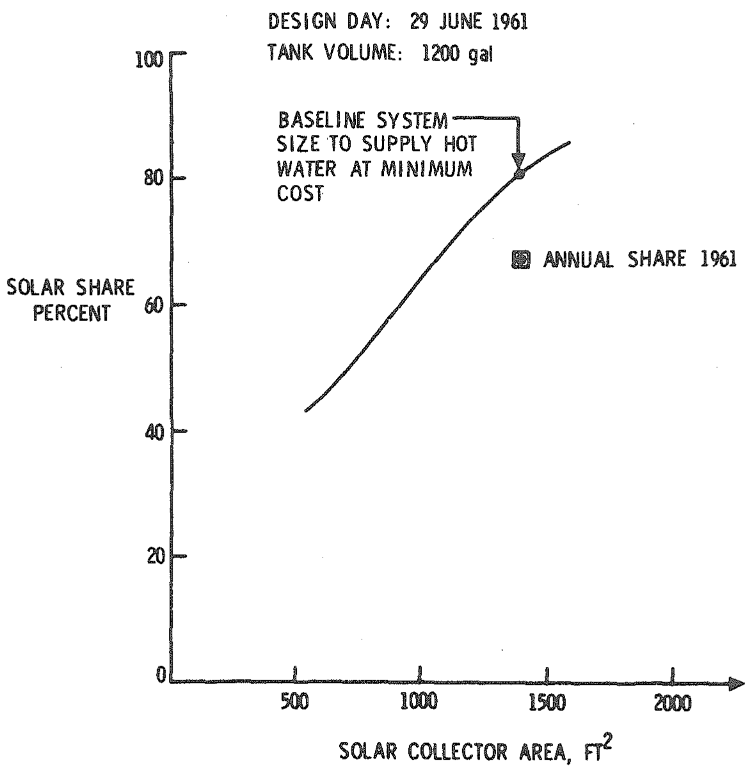


Figure 3-2

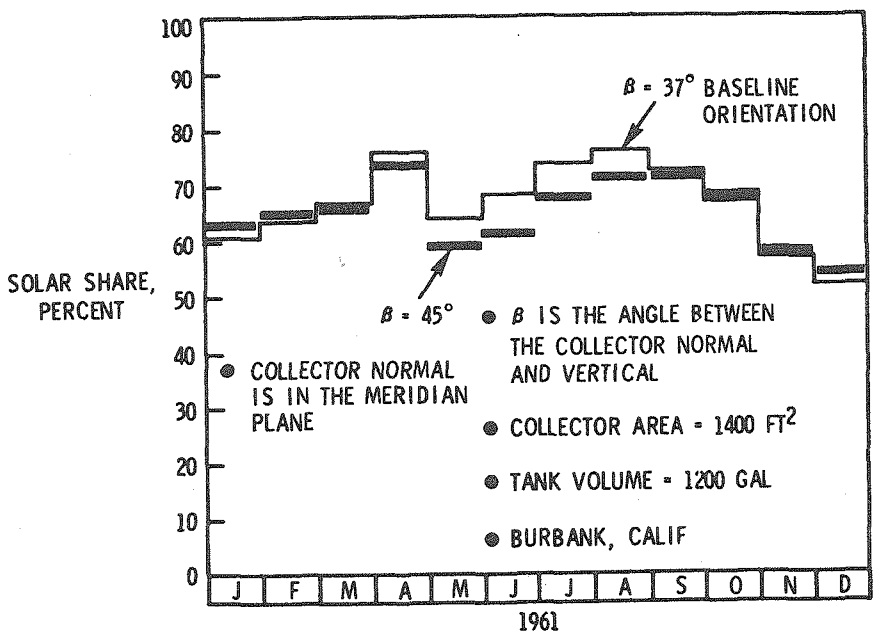
SHARE OF WATER HEATING LOAD CARRIED ON A CLEAR DAY



To a gas utility, the seasonal and hourly variation in demand for auxiliary fuel is important. A preliminary evaluation of the demand for auxiliary fuel has been made using a simulation model of the system. Using hourly weather observations from the weather station at Burbank, California, for the year 1961 (a year with a space space heating requirement typical of the long-term average for the Southern California Gas Company territory), performance of the baseline system was simulated with a time interval of 20 minutes. For this simulation, the daily demand for each day of the year was assumed to be 58 gallons per day per apartment unit, and the cold water inlet was assumed to be constant at 60°F. A single, typical average hourly demand profile (Ref. 1) was used for all days of the simulation. The results of this simulation are presented in Figures 3-3 and 3-4.

Figure 3-3 shows that the monthly share of water heating carried by solar energy varied between a low of 52 percent in December to a high of 77 percent in April for the year 1961.* Although this simulation is for one year only, it is clear that variability of the weather from month to month is about as significant as variability in solar geometry. In any case, the seasonal variation in demand for natural gas as an auxiliary fuel is only mildly significant.

Figure 3-3
SHARE OF WATER HEATING LOAD CARRIED BY SOLAR ENERGY



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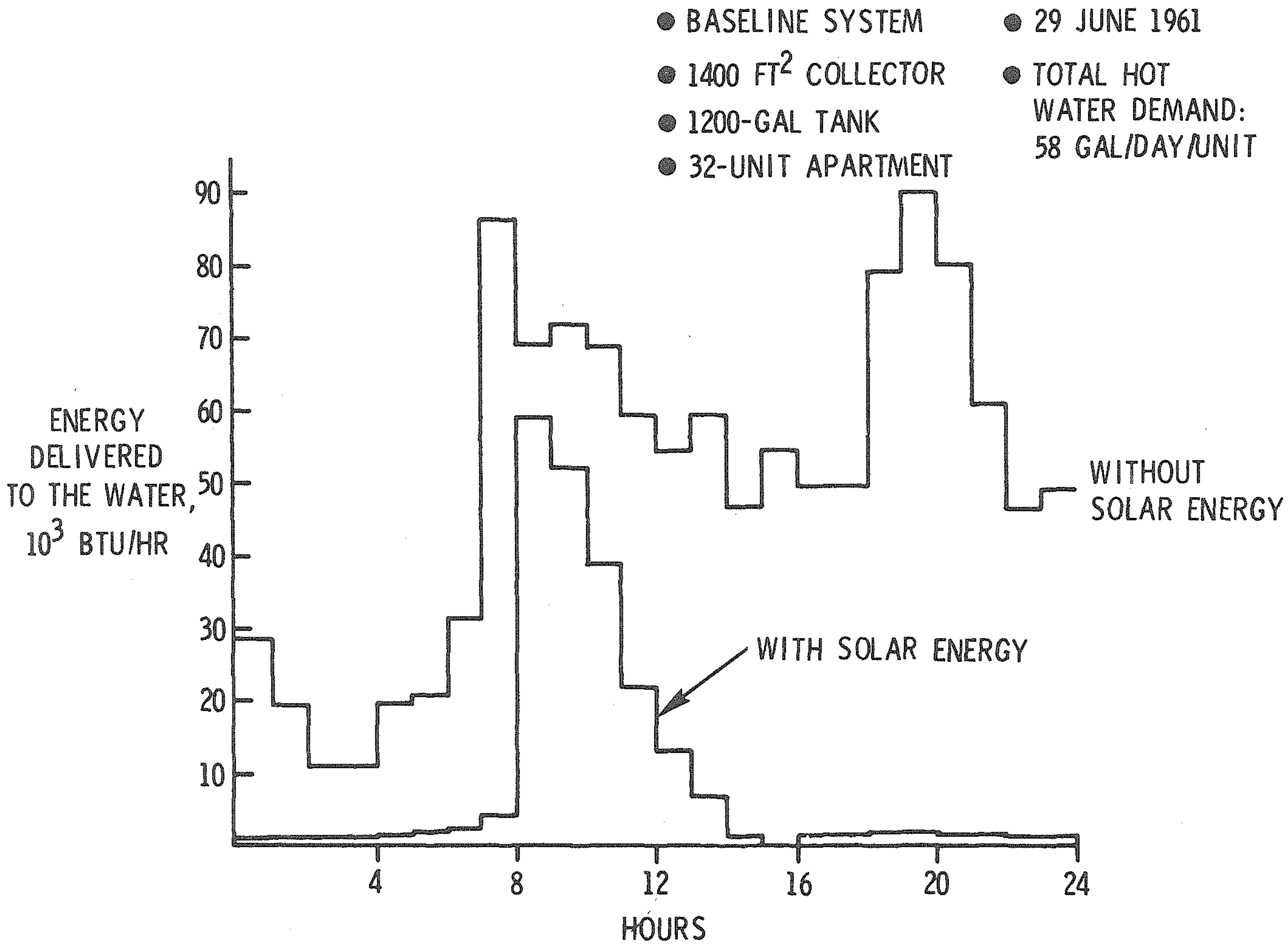
* Based on Australian experience,long-term performance dehydration due to dirt, etc., is not expected to exceed 5 percent.

The relatively steady nature of the supply of solar energy when averaged over one month is very important. On the order of 78 percent of the solar energy collected by the system in 1961 could have directly displaced production and transmission capacity in the gas utility system. Thus the "steady supply" component of solar energy is more significant then the "when available" component in the water heating application.

Figure 3-4 compares the hourly demand for auxiliary fuel with the hourly demand for energy to heat water on the design day 29 June 1961. This estimate of auxiliary fuel demand predicts a peak in demand early in the morning because of the mathematical model used for the system. In a real system, where the tank stratifies, the peak would be reduced and delayed until later in the morning. In addition, the sizes of the storage tank and solar collector are important to the nature of the hourly demand profile. Decreasing the size of the solar energy system will result in total dependency on auxiliary fuel during the early morning peak. Increasing the size of the system will delay the peak time until later in the morning. Thus, it is possible to design a solar water heating system so that the demand for auxiliary fuel occurs after the normal 7 to 8 a.m. peak demand for natural gas.

Figure 3-4

HOURLY DEMAND FOR NATURAL GAS



SECTION IV

COST ESTIMATES

In estimating costs there has been an attempt to take a conservative and consistent approach. At this point, some of the estimated costs might ultimately be reduced, hopefully by enough to make up for any omissions that might have been made in this study.

In order to keep track of the estimated system cost during the course of the study, the following cost estimating ground rules were established:

1. All bids for conventional plumbing were obtained from the same contractor.
2. List prices were used for all off-the-shelf hardware.
3. The costs of fabricated parts were estimated from sketches in 5000-unit quantities.
4. Building modifications were estimated from sketches.
5. The cost of the collector was arbitrarily held at $3 per square-foot for two-fluid systems, and $4 per square-foot for one-fluid systems in order to permit comparisons between alternate systems.
6. All costs are in 1973 dollars.

JPL Plant Engineering and Fabrication services estimated the cost of supplying building interface modifications and tie-down hardware capable of withstanding 80-mph wind loading.

The plumbing diagram shown in Figure 4-1 and the parts list, Table 4-1, are for the baseline system. Cost estimates for two different plumbing configurations were obtained from a plumbing contractor. Figure 4-1 is a composite, incorporating the best features of the two configurations submitted for cost estimates.

Figure 4-1

SOLAR ASSISTED GAS ENERGY WATER HEATER PLUMBING DIAGRAM

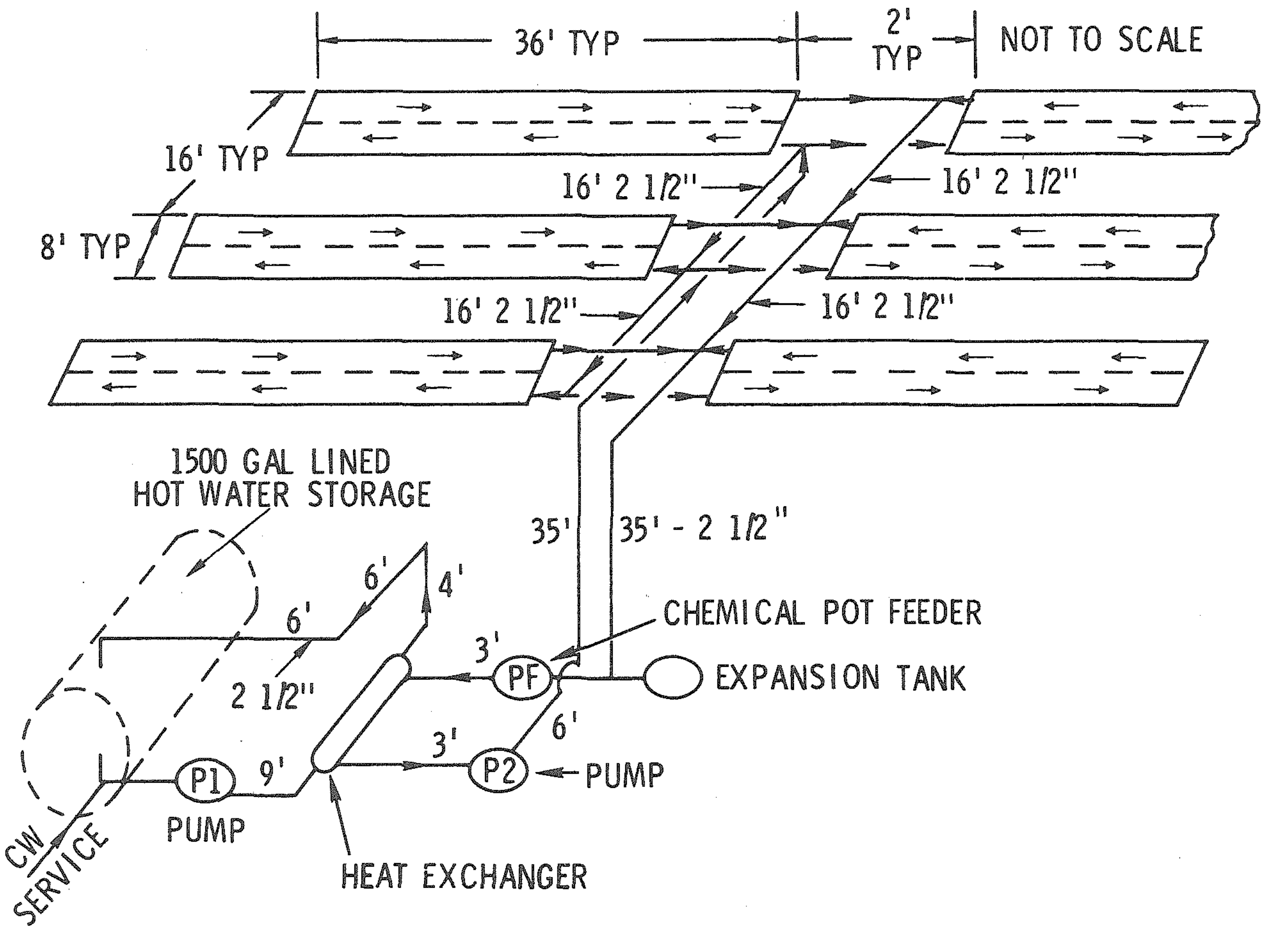


Table 4-1. Baseline Sage Water Heater Parts List

Part	Material	Size
HW Storage Tank	ASME Code Galvanized	1200 Gal
Pipe, 2-1/2"	Plastic	221 Ft
Pipe, 2"	Plastic	42 Ft
WU-68-44 Heat Exchanger	Brass Hd & Tube Sh	36.2 Ft^2
1/6 HP 2" Pump	Iron	40 GPM at 8 Ft of H_2O
1/6 HP 2" Pump	Bronze	30 GPM at 9.2 Ft of H_2O
Expansion Tank	Iron	12 Gal
Chem Feeder	Iron	Small
Solar Panel Support Pads	Iron-24 Reqd	1 Ft High
Roof Jacks for Sup. Pads	Sh. Metal	6"
Solar Collector Assembly		1400 Ft^2

A breakdown of the cost of the baseline system by component is shown in the first three columns of Table 4-2. The primary differences between configurations 1 and 3 of the baseline system is the length of pipe used to connect the system, and the use of a galvanized storage tank. Plastic pipe is also used in configuration 3. The use of a plastic pipe reduced the cost by less then $500.

Table 4-2. Estimated Cost: History and Projections

System Configuration	Phase History			Projected Cost		
	S1 First Layout	S1 Revised Layout	S1 Optimized Sizing	S2	S3	S4
Tank	4.1	3.8	3.1	0.5	3.8	0.5
Plumbing	4.3	1.7	1.7	1.1	1.0	1.0
Hx	1.1	1.1	1.1	--	--	--
Misc	0.7	0.7	0.7	--	--	--
Collector						
Material	5.1	5.1	4.2	4.2	4.8	4.2
Bldg. Pads	1.0	1.0	0.9	0.9	0.9	0.9
Install.	0.4	0.4	0.6	0.6	0.6	0.6
Total Cost	16.7 K	13.8 K	12.3 K	9.0 K	11.1 K	7.7 K
Notes:						
Tank	HEBCO 1500 Gal	GALV 1500	1200	Low Press	GALV 1500	Low Press
Plumbing						
Iron	720'	0	0	0	0	0
CU	25'	0	0	0	0	0
Plastic	0	263'	263	Lower Bid	Lower Bid	Lower Bid
Collector	1700 ft^2 Al	1700 ft^2 Al	1400 ft^2 Al	1400 ft^2 Al	1200 ft^2 Stainless Steel	1400 ft^2 Al
Heat Exchanger	Forced	Forced	Forced	4x Capacity	--	Natural
Annual % S.E.	Est. 70%	Est. 70%	67%	?	67%	?

Cost estimates projected for Systems S2, S3, and S4 are "best engineering guesses" for what might be achieved for tanks, plumbing, and heat exchangers. In making these guesses, the ground rules established for the baseline system were kept in mind. Thus, we feel that total installed systems costs in the range of $8000 to $9000 could be achieved with little or no research, but some development effort. This total cost represents a cost of $250 to $300 per apartment unit. For comparison the cost of a central gas water heating system for a 32-unit apartment would be about $50 per unit, while the cost of individual electric water heaters would be about $260 per unit. In all cases the cost is a small fraction of the cost of an individual apartment unit.

The price of the "non-collector" part of the system is at least two to three times more expensive than our early estimates which were based on available data in solar energy literature. We suspect that differences are caused by: (1) confusion on the part of many investigators between "cost to manufacture" and "installed cost," (2) failure to accurately consider installation problems, and (3) failure to include the cost of building interface modifications.

SECTION V

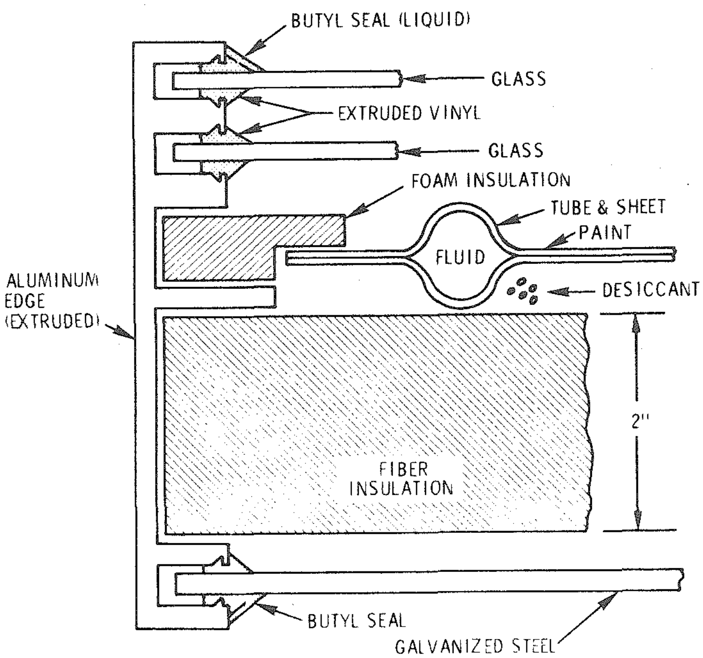
SOLAR COLLECTORS

The fundamental engineering design equations for flat plate solar collectors have been established and published. (See Ref. 4) A double glazed flat plate collector from Reference 4 was used for the baseline system. The principal issues for the solar collector relate to design and cost. The solar collector is the only major system component that is not a standard commercial product. Our initial study indicates that a $3/ft^2 to $4/ft^2 high performance, long-life solar collector is feasible when manufactured in a manner similar to that of aluminum frame windows. In addition, several alternate design approaches exist for the absorber, the glazing, and the module construction which promise to reduce costs and simplify the system.

An edge detail of the baseline solar collector design is illustrated in Figure 5-1. It is a flat (non-focusing) collector with double-glass glazing, Alclad aluminum "tube-in-sheet" absorber, Fiberglas insulation with a galvanized steel bottom and an extruded aluminum edge. Extruded vinyl is used to hold the glass, but liquid butyl provides the low-moisture penetration seal. A paint which has high solar absorptivity is used on the absorber. The Alclad tube-in-sheet absorber was chosen due to low cost ($0.80/ft^2), availability, and high thermal performance. However, a corrosion inhibitor is required if water is used for the fluid. Suitable corrosion inhibitors currently used in similar application are toxic. This will require special qualifications for this system. In addition, periodic inspections of fluid chemistry are currently conducted to guarantee long life.

Figure 5-1

SOLAR COLLECTOR ASSEMBLY



Two module sizes are considered: a 4' x 4' module using single-strength glass (SS); and a 4' x 6.5' module using a double-strength glass (DS). Structural considerations limit the use of single-strength glass to an unsupported area of 16 ft^2. In both cases, two 2' wide tube-in-sheet panels are used with two internal connections so that there are about ten parallel 3/8" diameter tubes with an inlet and outlet header.

Module price estimates were made in collaboration with a potential manufacturer of solar collectors who currently manufactures aluminum frame windows. The assembly approach is based on aluminum-framed window manufacturing practice, where the extruded aluminum edge is the key to low labor costs. This solar module is essentially a triple-glazed window (two sheets of glass and one steel plate) with two additional internal layers; the tube-in-sheet, and the insulation. Detailed estimates of collector costs are shown in Table 5-1. The total represents the price of the module delivered to the construction site.

TABLE 5-1. Collector Module Price Estimate

Component	Estimated Price $/ft^2 Module Size 4' x 6.5'	4' x 4'	Source of Estimate
Material			
Double Glass	$0.66	$0.31	Quantity cost to a window manufacturer 10% waste allowance
Tube-in-Sheet	0.93	0.93	Olin Brass Rollbond Div. (including inlet and outlet ports and shipping)
Insulation	0.10	0.10	Owens Corning Fiberglas
Steel Bottom	0.25	0.25	.020 at $0.33 per pound
Al Edge	0.10	0.10	Estimated cost by window manufacturer
Misc	0.10	0.10	Author estimate
Assembly Labor	0.40	0.25	Author estimate
Overhead & Profits	0.85	0.68	33% of labor and material: current practice in window manufacturing
Shipping	0.50	0.43	$0.09 per pound
Total	$3.89/ft^2	$3.15/ft^2	Total corroborated by manufacturer

The price of the collector presented here could be achieved in the first year of production. A minimum sized assembly line of 4 men producing collectors adequate for 5,000 apartment units per year is assumed in the price estimate in Table 5-1. The first year's production would be a reasonable entry point to the Southern California apartment market where approximately 70,000 apartment units are being constructed each year.

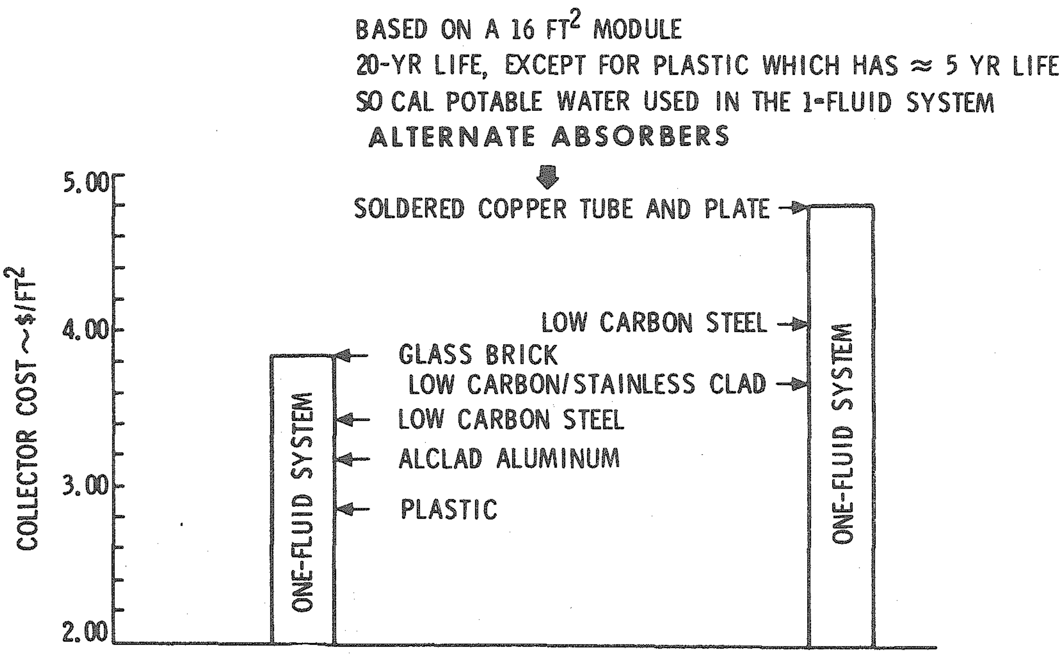
The price of the collector does not include any markup between the price of the collector delivered to the site by the manufacturer and the ultimate owner of the system. The price, therefore, assumes that the owner of the completed system places the order for the collector. This is in contrast to all commercial components which are ordered and delivered by the plumbing contractor.

Alternate glazing (e. g., Fiberglas and rigid or flexible plastic) is similar in cost to glass, but has a more limited life. However, this may be important if vandalism should be a more significant consideration than it is for windows.

Alternate absorbers to replace the Alclad tube-in-sheet in a two-fluid system are: low-carbon steel (LCS) tube-in-sheet, extruded plastic or all glass. The LCS is about the same cost, but may have less severe corrosion prevention problems. The plastic and glass are in the same price range and require no corrosion inhibitors. Absorbers for one-fluid systems could be made of materials compatible with potable water; copper or low-carbon steel clad with stainless steel. The corrosion rates of Southern California water favor the use of stainless steel cladding. The current best estimates of the total collector cost per sq. foot is compared for various absorber materials in Figure 5-2. All of the materials listed on Figure 5-2 merit further evaluation to determine their characteristics and cost.

Figure 5-2

ESTIMATED SOLAR COLLECTOR COST



Alternate modules could be made entirely of plastic (extruded or flexible). These hold the promise of significantly reducing collector costs, but require a greater materials development program. Even an all-glass collector is possible and should be explored.

SECTION VI

ANALYSIS OF ECONOMIC FEASIBILITY

An analysis of the economic feasibility of solar water heating was made from the viewpoint of a gas utility company. Although the exact nature of the solar energy business operation of a gas utility was not investigated, two options where the utility retains ownership of the equipment were considered. The first option involves offering the equipment on a lease service contract. The second option involves expansion of the existing natural gas energy business to include the supply of solar energy. We call this second option the "energy service" option. In either case, the capital investment made by the utility in solar energy equipment must be paid for by revenues collected or reductions in costs. For both options the basic criteria for investment is the same.

A solar-assisted gas water heater requires full back-up capacity from gas. Therefore, there are no reductions in the cost of the distribution system. If the consumer is to pay the same for his energy services, the total investment in installing solar water heating equipment must be recouped from savings in natural gas. If a gas utility is making this investment, approximately 78 percent of the savings of natural gas must be valued at the cost of new baseload supplies of natural gas, while the remaining savings is valued at the price of gas to the interruptible customers. However, because this interruptible factor is small it can be neglected in evaluating the feasibility of solar water heating.

In order to make a preliminary estimate of economic feasibility, an interest rate and an estimate of the system life are needed. In this study capital is amortized in 10 years with an interest rate of 16.2 percent.* This interest rate permits a utility company to make disburesments to: (1) creditors at 8 percent interest, (2) government at an income tax rate of 52.7 percent of profits and an ad valorem tax rate of 2.5 percent on capital investment, while (3) providing for a target rate of return 13 percent on equity capital. A ratio of debt-to-investor equity of 1.0 is assumed. Although the system as presently designed should last longer than 10 years, the 10-year life is assumed for two reasons: (1) lacking sufficient information on maintenance requirements, we assumed no maintenance, with complete system failure after 10 years, and (2) the assumption of a 10-year life is typical for similar equipment, and is in accord with conservative investment practice.

Figure 6-1 shows the value of fuel for which the investment in solar water heating for a 32-unit apartment is amortized by the fuel saving. Two curves are shown, depending on whether or not solar energy is supplied to the circulation line loss. From Figure 6-1 it is clear that the baseline system would be an attractive investment for a gas utility if the value of the gas saved is \$5 per 10^6 BTUs. If the best engineering guess of the cost of system S4 is correct, solar water heating could be attractive if the value of natural gas were in the range of \$2.50 per 10^6 BTUs to \$3 per 10^6 BTUs.

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* This amortization schedule results in a ratio of $\frac{\text{(annual cost)}}{\text{(capital cost)}} = .21$.

Figure 6-1

VALUE OF FUEL TO AMORTIZE AN INVESTMENT IN SOLAR WATER HEATING

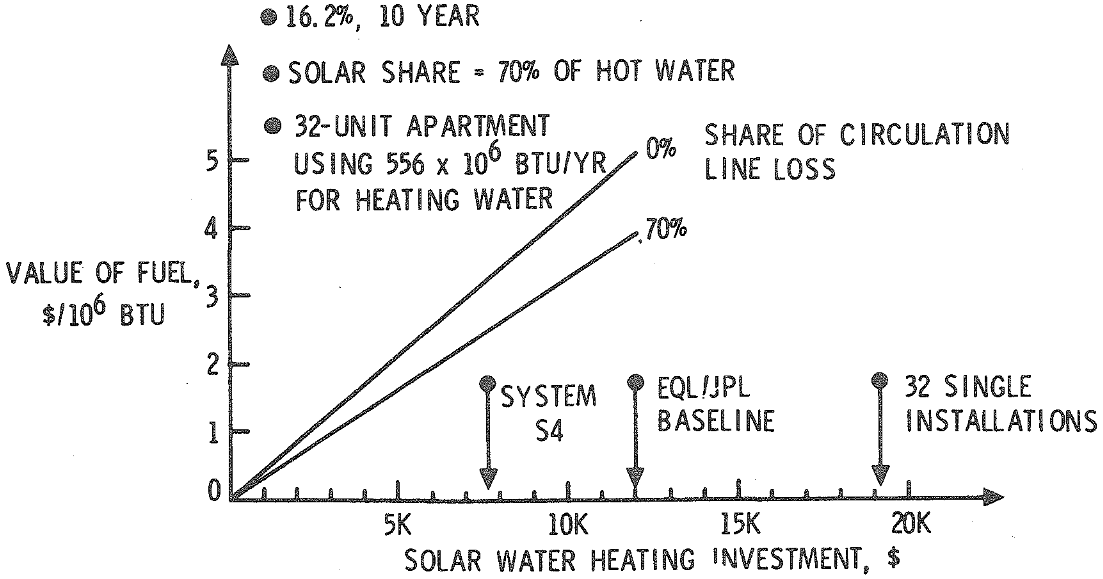


Figure 6-1 is also used to estimate target costs for a solar water heating system for a 32-unit apartment. In order for solar water heating to look attractive when compared to gas, whose average value is \$1.50 per 10^6 BTUs, it is necessary to design the system to cost in the range of \$3700 to \$4600 for a 32-unit apartment. The exact target cost will depend on the share of the circulation line loss which can be carried by solar energy. With system S4 estimated to cost \$7700 for the study building, solar water heating is not competitive with \$1.50 natural gas on a price basis, but it is within range of economic feasibility.

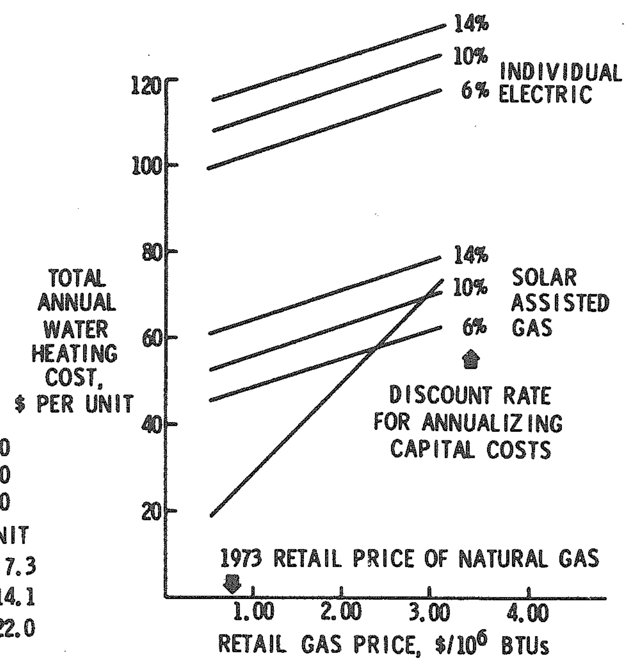
The foregoing discussion has focused on the attractiveness of solar water heating as an investment for a gas utility where the utility retains ownership. If the solar water heating systems were sold to apartment owners then different interest rates would be appropriate. In Figure 6-2 the annual cost of heating water by solar energy is compared to the two dominant alternatives in Southern California — individual electric and central gas. Although solar water heating is currently much less expensive than individual electric water heating, it would be more expensive than central gas water heating at current gas prices of \$.76 per 10^6 BTUs. In order for solar water heating to be less expensive than central gas the retail price of gas would need to be approximately \$3 per 10^6 BTUs.

Figure 6-2

THE COST OF ALTERNATE METHODS FOR WATER HEATING

ASSUMPTIONS:

- SYSTEM LIFE
  - 10 YEARS
- APARTMENT SIZE
  - 32 UNITS
- ELECTRICAL ENERGY COST
  - \$4.30 + 1/2 RETAIL GAS COST, $\$/10^6$ BTU
- EQUIPMENT COST, \$/UNIT
  - SOLAR ASSISTED GAS 300
  - INDIVIDUAL ELECTRIC 260
  - CENTRAL GAS 50
- ENERGY USEABLE, 10^6 BTU/YR/UNIT
  - SOLAR ASSISTED GAS 7.3
  - INDIVIDUAL ELECTRIC 14.1
  - CENTRAL GAS 22.0



SECTION VII

CHARACTERISTICS OF NEW APARTMENT BUILDINGS IN PART OF LOS ANGELES COUNTY

In order to help to relate the conclusions for a solar water heating system designed for a specific apartment in Pasadena to the total market, a study of the characteristics of apartment buildings in the South Coast Air Basin was performed. The objectives of the study were: (1) to determine if the baseline three-story apartment was typical of apartment buildings in the Basin and (2) to characterize the range of new apartments being built in the Basin. The study consisted of a survey of new building permits issued by the Los Angeles County Department of Building and Safety. These permits are issued for an area including 20 unincorporated areas and 31 contract cities in Los Angeles County.

In addition, the summary data on building activity prepared by Security Pacific National Bank were analyzed (See Ref. 5). Since Security Pacific prepares monthly and yearly reports, we hoped to be able to use their summaries; however, their summary includes only the building activity valued at over $100, 000. The survey was performed to provide a check to see how much of the building activity is over/under $100, 000.

The complete building permit data for five randomly selected months were collected and analyzed. The months were selected from a 16-month period, from January 1972 to April 1973 inclusive. The five-month sample includes about 33 percent of the total number of annual units generated for the area surveyed. Figure 7-1 illustrates the sample survey in terms of the areas included, the types of units, and the months selected. The survey data included 693 projects, with a total of 6440 units. Of the total survey units, 4822 units or 75 percent were for multiple-family dwellings (duplex, triplex, and larger).

Figure 7-1

SURVEY SAMPLE DESCRIPTION

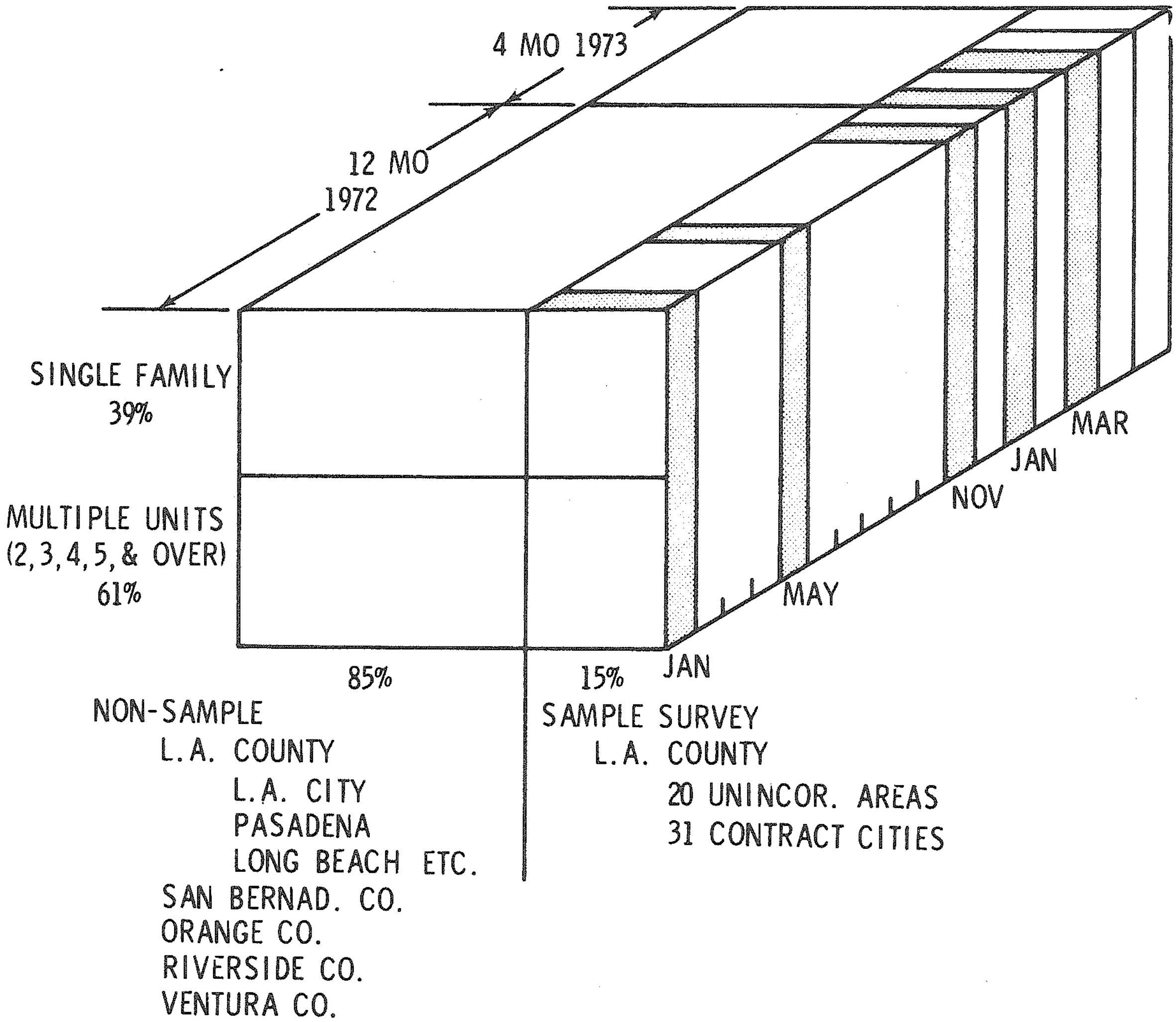


Table 7-1 compares the units in the sample with the totals for: (1) L.A. County Department of Building and Safety, (2) Los Angeles County total, and (3) the five county South Coast Air Basin total.

Table 7-1. Survey Sample Compared to Existing Summaries

	Time	Units	Single Family	Multiple Family	% of Totals
Sample Survey (Uninc + 31 Cities)	5 mo	6,440	1618 (25%)	4822 (75%)	38% of area
L.A. County (Uninc + 31 Cities)	12 mo	17,240	6560 (38%)	10,680 (62%)	33% of County total
L.A. County total	12 mo	53,100	10,805 (20%)	42,295 (80%)	45% of SCAB total
SCAB (5 County total)	12 mo	116,328	44,204 (38%)	72,123 (62%)	

We classified apartment buildings into seven size categories: buildings having: (1) 2 to 4 units, (2) 5 to 10 units, (3) 11 to 20 units, (4) 21 to 50 units, (5) 51 to 80 units, (6) 81 to 100 units, and (7) over 100 units. Figure 7-2 displays the number and percentage of units in each apartment- building-size category for all the multiple units in the sample. Figure 7-3 displays the number of units in each apartment category for two-story multiple units.

Comparing Figures 7-2 and 7-3, a predominance of two-story construction is apparent. Over 66 percent of the units in the sample are in two-story buildings. Only 12 percent of the units in the sample are similar to the study building in having 3 stories and more than 20 units per building. We feel that the sample is biased toward the two-story building because high land-value cities are not included in the sample. However, two-story apartments appear to be an important market for solar water heating and should be examined in more detail.

Figure 7-2

CLASSIFICATION OF ALL APARTMENTS BY SIZE

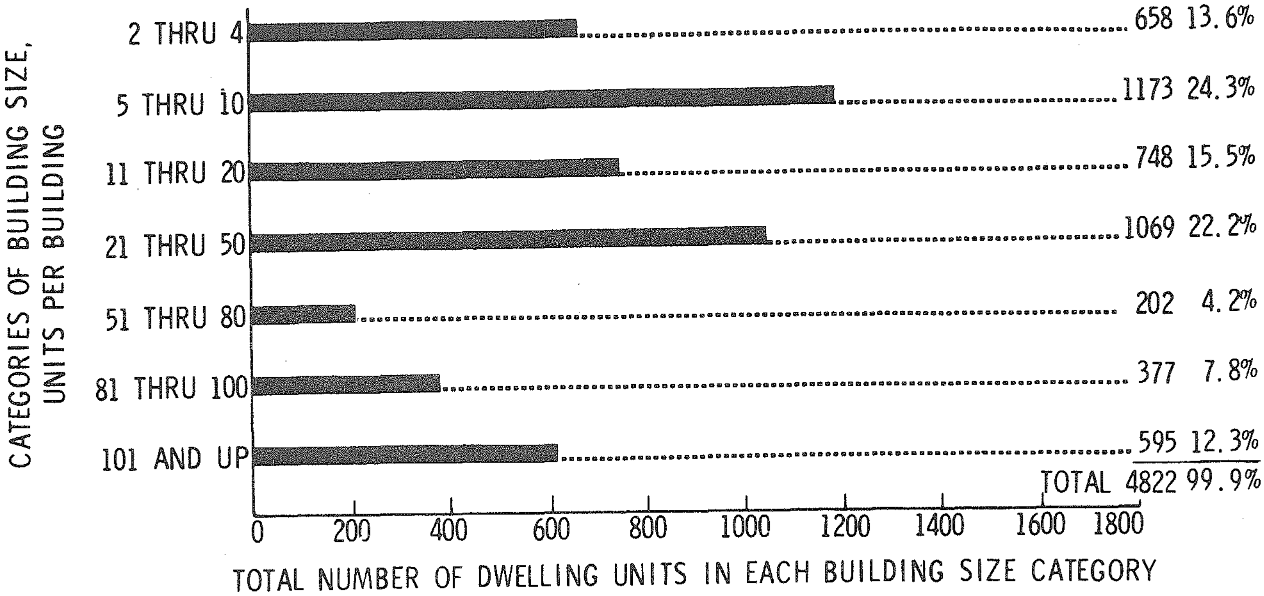
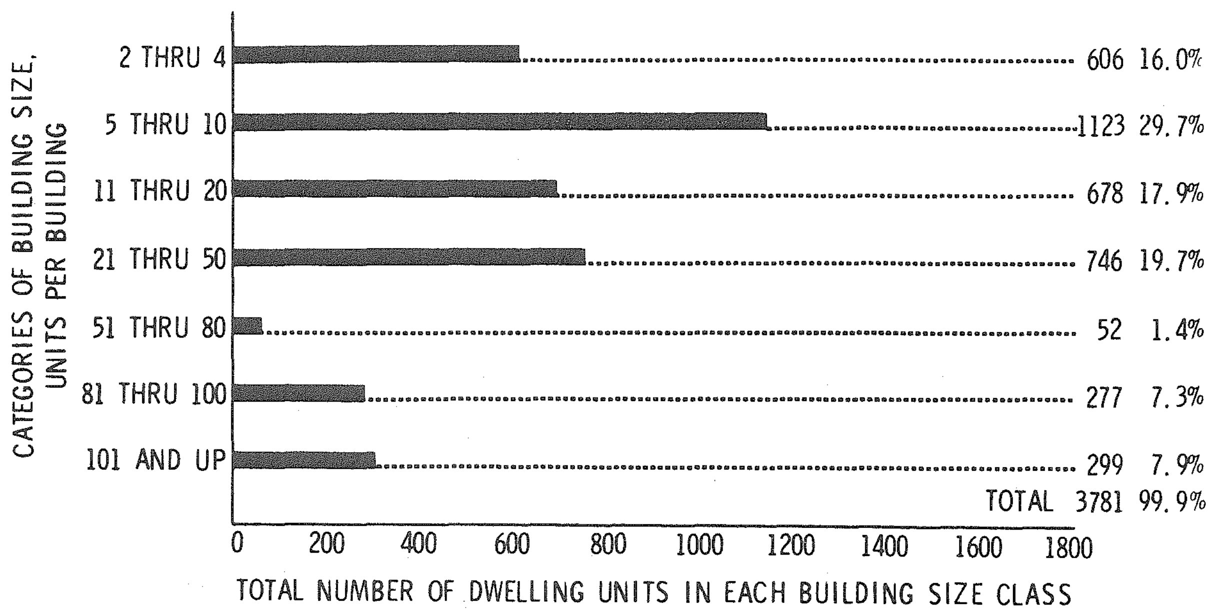


Figure 7-3

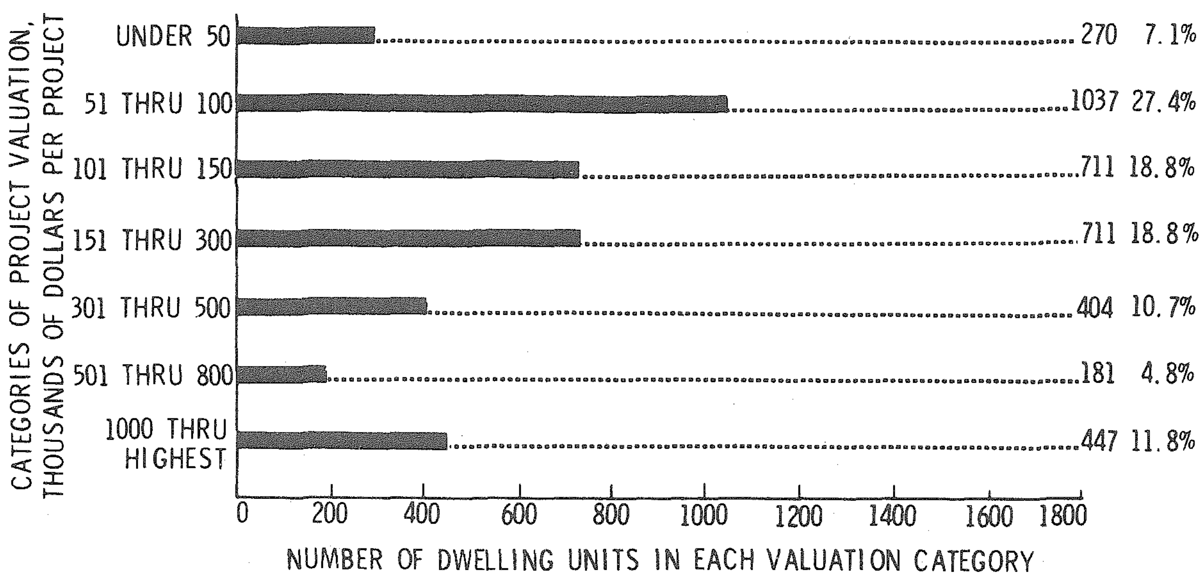
CLASSIFICATION OF ALL TWO STORY APARTMENTS BY SIZE



There is a very significant range in the size of apartment buildings; however, most of the activity is in smaller buildings. For the two-story buildings in the sample, two-thirds of the units are in buildings ranging from 5 to 50 units, but single buildings with over 100 units are also being built.

Figure 7-4 is a histogram of the total project value (as given on the permit) for two-story multiple units. Figure 7-4 shows that a significant amount (35%) of multiple-unit projects are valued at under $100,000. Thus, the survey shows that one must use extreme caution with the summary data (over $100K) prepared by the County and Security Pacific National Bank. In addition, this survey can be viewed as a pretest for a more extensive and representative sample that will characterize the entire South Coast Air Basin (SCAB) area.

Figure 7-4
CLASSIFICATION OF ALL TWO STORY APARTMENTS BY VALUATION



SECTION VIII

CONCLUSIONS

Our study of a solar-assisted gas energy water heating system for the apartment building in Pasadena has led us to the conclusion that there are no technical barriers to the implementation of solar water heating in Southern California apartments. While solar water heating is currently somewhat more expensive than heating water with natural gas, solar water heating is less expensive than electric water heating.

Solar water heating in Southern California will become competitive with all-gas water heating when the value of the fuel saved is on the order of \$2.50 to \$3.00 per 10^6 BTUs. By comparison, the current marginal cost of gas to an apartment is \$.76 per 10^6 BTUs. Although it does not appear that solar water heating will be competitive on a price basis with natural gas in this decade, it is within the range of economic feasibility. Roughly one-sixth of the new apartments are choosing electric water heating. The current marginal cost for electric energy exceeds \$5.00 per 10^6 BTUs.

In a large area of Southern California, over two-thirds of the natural gas consumed directly in water heating could be saved by the use of solar energy. On a month-to-month basis, the share of water heating provided by solar energy can be expected to range from 50 percent to 80 percent. This conclusion is expected to be valid over the whole southern United States.

Since solar energy can supply the major share of energy for water heating year round, utilization of solar energy can directly reduce the growth in baseload demand for natural gas. A corresponding reduction in requirements for a new gas supply would also be indicated. Therefore, solar water heating will become economically interesting to a gas utility as a commercial venture when the cost of additional supplies of natural gas approaches a level of \$2.50 to \$3.00 per 10^6 BTUs, or when consumers place a value on the use of solar energy which makes up the difference between the price of natural gas and \$2.50 to \$3.00 per 10^6 BTUs.

The auxiliary fuel required for an economically optimized system can be readily supplied by a gas utility company. The seasonal variation in demand for auxiliary fuel is only mildly significant. Solar energy can carry the major part of the water heating load in all months of the year in Southern California. It is also possible to design the solar energy system so that its peak hourly demand for natural gas occurs between 9 and 10 a.m., thereby avoiding the 7 to 8 a.m. peak demand for other natural gas.

The two major components of the system, the collector and the storage tank, need further development. The most critical need is for a low-cost, high-performance solar collector. Our survey of existing manufacturing techniques indicates that, with existing industrial techniques, a solar collector suitable for use with a two-fluid system can be delivered to the construction site for a price of approximately \$3 per square foot. Detailed production design and engineering is required to confirm this estimate. A significant collector cost breakthrough to a cost of \$1 per square foot may be possible, if an all-plastic collector can be developed. A second component needing development is the storage tank. We do not have an adequate mathematical model of the operation of a tank, including the stratification phenomenon. Lack of an accurate tank model limits our ability to accurately predict the operation of the system. In addition, the cost of storing energy in a tank of domestic water at the pressure of the supply main is very high. A low cost energy storage system is needed.

SECTION IX

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APPENDIX A

BASELINE SYSTEM PARAMETERS

Collector

Collector plate width	215.4 feet
Collector plate length	6.5 feet
Collector plate thickness	.12 inch
Collector plate conductivity	129 BTU/hr ft°F
Collector plate absorbtivity	.92
Collector plate emissivity	.92
Number of tubes	539
Collector tube diameter	.375 inch
Number of glazing layers	2
Thickness outer glass	.125 inch
Thickness inner glass	.094 inch
Glass extinction coefficient	.583 $inch^{-1}$
Glass index of refraction	1.526
Glass emissivity	.9
Collector insulation thickness	2 inches
Collector insulation conductivity	0.03 BTU/hr ft°F
Collector normal zenith angle	37 degrees
Collector normal azimuth angle	south

Storage Tank

Tank volume	1200 gallons
Tank diameter	4 feet
Tank insulation thickness	4 inches
Tank insulation coefficient	.03 BTU/hr ft°F

Heat Transfer

U-value of heat exchanger	342 BTU/hr ft^2°F
Area of heat exchanger	36.2 $feet^2$
Collector plate flow rate	40 GPM
Tank side flow rate	30 GPM
Temperature Control Dead Band	5 °F

Water

Temperature of hot water	140 °F
Temperature of make up water	60 °F

Gas Boiler

Boiler efficiency	.8