PROJECT SAGE

Solar Assisted Gas Energy

Interim Report Number Two
CCMS Solar Energy Pilot Study

August, 1976

Sponsored by

Southern California Gas Company
National Science Foundation/RANN
Federal Energy Administration
Energy Research and Development Agency

Principle Consultant

Jet Propulsion Laboratory, Pasadena, Calif.

This CCMS (Committee on the Challenges of Modern Society)
report was prepared under a separate work order for the,
Energy Research and Development Agency.

JPL Document 5030-34

PROJECT SAGE

SOLAR ASSISTED GAS ENERGY PROJECT

A Utility Business Proof of Concept Experiment

Authors:
A. Hirshberg
R. Barbieri
R. Bartera
J. Lingwall
R. Schoen
R. Vault

James F. Rice
J. Rice, Project Manager
Southern California Gas Company
810 So. Flower Street
Los Angeles, California

Alan S. Hirshberg
A. Hirshberg, Project Manager
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

Prepared for the United States
Energy Research and Development Administration
Division of Solar Energy

CONTENTS

CONTENTS (contd)

TABLES

CONTENTS (contd)

TABLES (contd)

FIGURES

CONTENTS (contd)

FIGURES (contd)

INTRODUCTION

This report is being written for the NATO Committee on the Challenges of Modern Society (CCMS) program, Solar Energy Pilot Study. The purpose of the report is to give a preliminary description of Project SAGE, the solar assisted gas energy (SAGE) water heating system currently being tested and evaluated in Southern California.

The report, which follows the CCMS reporting format, contains a statement of the goals and objectives of the SAGE water heating program, a general description of the project in addition to system performance data, evaluations and economic analyses of the various pilot studies and field test installations.

> Southern California Gas Company does not represent that the parties named herein as manufacturers of the component parts used in this solar energy project are the only manufacturers of such products. Nor does Southern California Gas Company endorse the products manufactured by the parties named herein over those manufactured by any other party.

I. GENERAL DESCRIPTION OF TOTAL SYSTEM PROJECT AND ENVIRONMENT

A. OBJECTIVES OF PROJECT SAGE

Project SAGE is a four-phased plan to define the equipment design, cost requirements, government policies and initiatives, market requirements, and necessary institutional changes for the successful commercial application of solar assisted gas energy (SAGE) water heating.

Project SAGE developed out of a multidisciplinary effort focused on the broad problem of introducing solar energy in the U. S. building industry on a scale which could have a significant impact on the demand for fossil fuels. The regional character of the building industry led to focusing the effort in Southern California, one of the largest and fastest growing building markets in the world. Residential water heating is a significant consumer of energy in the Southern California area, consuming 27% of residential energy, or 6% of primary energy. Water heating is a fast growing user of energy, growing at over 5% per year. Water heating in apartments was found to be the least expensive application of solar energy and therefore the most likely to achieve commercial use in the near term. In addition, a mutually beneficial relationship between solar water heating and the gas utility industry was conceived because of both the projected future shortages of new gas supplies and their high marginal costs.

In the early part of 1973, Phase I of Project SAGE began when Southern California Gas Company (GASCO) entered into a contract with California Institute of Technology (Caltech) for a study of the technical and economic feasibility of SAGE water heating in Southern California. Additional NSF funding was provided for a study of relevant institutional questions such as the barriers to the use of solar energy by the building industry.

Phase II began in late 1973 when GASCO funded Caltech's Jet Propulsion Laboratory (JPL) to construct a pilot plant at JPL in Pasadena, California, to

1) select the most cost-effective configuration for the SAGE system and 2) develop specifications and identify suppliers for all the components. This phase was completed in mid-1974.

The overall goal of Phase III, which began in January 1975, is to determine the conditions necessary for solar assisted gas energy water heating for multifamily dwellings to become a viable business activity of a gas utility or an affiliated company. There are three parts to this phase:

(1) The field installations and tests which are being used to evaluate new vs retrofit installations;

(2) Market assessment of the potential for a SAGE water heating system and possible GASCO business arrangements; and

(3) Determination of the requirements for widespread utilization of solar energy using SAGE as a case study, and evaluation of alternative policies and strategies which would contribute to the widespread utilization of SAGE water heating.

If Phase III is successful in determining the viability of SAGE water heating, and if it is consistent with the goals and objectives of GASCO, Phase IV will be initiated. It is designed to be a trial commercial venture of SAGE water heating at a minimum scale of 5000 apartment buildings and 18,600 m^2 (200,000 ft^2) of collector area. This would begin in early 1977 and hopefully lead to a full commercialization of SAGE water heating.

Phase III is currently in progress and the remainder of this report will present data from Phase III, using the results of the Phase II (pilot plant) wherever they are relevant. In order to complete the objectives of Phase III a series of questions was asked:

(1) The specific objectives of the field test and installation is to perform a final shakeout of the technical design. The questions being addressed include:

- Is the prototype technical design the best for an apartment?
- How much fuel is actually saved by solar energy?
- What will it cost to install a SAGE water heater in an existing apartment building compared to a new apartment building?

- Recognizing the uncertainty in the demand for hot water — what is the best method for sizing SAGE water heating systems for new and existing installations?

(2) The Market Assessment Objective is to assess the potential market for SAGE water heating and test the possible GASCO business arrangements for SAGE water heating. Questions to be addressed include:

- Can SAGE water heating be profitably applied to other (non-apartment) market segments such as hospitals?
- What is the preferred ownership arrangement for SAGE water heating?
- What is the threshold size for a trial commercial venture?
- What market plan appears to be most likely to succeed?
- How will a GASCO business venture in solar energy be viewed by regulatory agencies and by other business firms?
- Are there better methods for commercializing SAGE water heating which might effectively drive a utility-based venture out of the marketplace.

(3) The utilization and policy analysis task comprises the third part of Phase III. This task is divided into two parts, each of which has different objectives.

(a) Establish requirements for widespread utilization of solar energy using SAGE water heating as a case study. Questions to be addressed include:

- What are the institutional (socio-legal) issues which might prevent large-scale commercialization of SAGE water heating (and other solar energy HVAC systems)?
- What socio-legal problems such as solar's sun rights emerge from the installation and field testing which would deter commercialization?
- What do the reactions of the building industry indicate about the requirements for successful SAGE water heating venture?

- What requirements for the widespread use of SAGE water heating emerge from the project?; and

b. Evaluate alternative policies and strategies contributing to the widespread use of SAGE water heating and other solar systems. Questions to be addressed include:

  - How much energy can be "saved" by SAGE water heating?
  - How fast is this saving likely to accrue?
  - Are there any major barriers to widespread use of SAGE water heating which require federal, state or local government policy initiatives?
  - What is the sensitivity of the rate of widespread utilization to alternative policies?

There are three installations in Southern California which are being evaluated in this Project SAGE report: the pilot plant in Pasadena and two field test installations - an existing apartment building (The Timbers) in El Toro and a new apartment building in Upland. Measured thermal performance data is only available for the pilot plant and 29 days at The Timbers. System cost information is available from both field tests plus the estimates from the pilot plant. Therefore, in the remainder of the report, system thermal performance will be given for just the pilot plant and the Timbers while the economic analysis will contain information from all three installations.

B. DESCRIPTION OF THE ENVIRONMENT

1. Climate

The pilot plant in Pasadena and The Timbers in El Toro are located in Southern California, an area classified by Trewartha[1] as "Cs" - subtropical with dry summers. As shown in Tables 1 and 2 most of the precipitation occurs within a short period in the winter with less than 2% of the rain falling in the summer. Winters are mild, usually above freezing and the days are generally sunny with clear skies. High coastal fog occurs frequently in early summer; however, it generally burns off by early morning.

Table 1. Climatological Data (10-13 Year Observations): Burbank/Pasadena, California

	Mean Monthly Precipitation mm (in.)	Mean Daily Insolation Kwh/m^2 (Btu/ft^2)	Mean Monthly Temperatures °C(°F)	Mean Relative Humidity %	Mean Degree Days °C(°F)	
					Heating	Cooling
January	102.36 (4.03)	2.82 (895.3)	13.3 (55.9)	61	192.5 (346.6)	0.0 (0.0)
February	52.07 (2.05)	3.62 (1147.5)	12.9 (55.3)	58	152.7 (274.8)	0.0 (0.0)
March	39.37 (1.55)	5.07 (1605.9)	14.2 (57.5)	59	132.1 (237.7)	0.0 (0.0)
April	39.37 (1.55)	6.25 (1982.3)	16.6 (61.8)	63	76 (136.8)	0.4 (0.8)
May	6.60 (0.26)	6.25 (1980.4)	16.8 (62.2)	64	63.7 (114.7)	0.1 (0.1)
June	0.25 (0.01)	6.75 (2141.4)	19.2 (66.6)	66	22.2 (39.9)	1.6 (2.8)
July	0.00 (0.00)	7.27 (2303.7)	22.3 (72.1)	62	0.6 (1.1)	14.4 (26.0)
August	1.27 (0.05)	6.62 (2098.8)	22.3 (72.1)	63	0.0 (0.0)	11.6 (20.9)
September	2.03 (0.08)	5.35 (1696.2)	18.6 (65.4)	60	2.7 (4.9)	20.8 (37.4)
October	9.40 (0.37)	4.16 (1317.7)	16.9 (62.4)	61	33.8 (60.9)	3.3 (5.9)
November	34.29 (1.35)	3.08 (975.6)	13.2 (55.8)	54	109.2 (196.6)	0.1 (0.1)
December	37.59 (1.48)	2.64 (839.2)	11.5 (52.7)	53	172.6 (310.7)	0.0 (0.0)
Annual	325.12 (12.8)	4.99 (1318.4)	16.5 (61.7)	60	958.1 (1724.6)	52.3 (94.1)

*Burbank, the nearest weather bureau station, is less than 20 km from Pasadena.

Table 2. Climatological Data (10-13 year observations): El Toro, California

	Mean Monthly Precipitation mm (in.)	Mean Monthly Insolation Kwh/m^2 (Btu/ft^2)	Mean Monthly Temperatures °C(°F)	Mean Relative Humidity %	Mean Degree Days °C(°F)	
					Heating	Cooling
January	91.95 (3.62)	2.47 (783)	11.9 (53.5)	69	200.0 (360.0)	0.0 (0.0)
February	53.09 (2.09)	3.35 (1063)	13.1 (55.5)	67	151.1 (271.9)	0.0 (0.0)
March	50.80 (2.00)	4.76 (1510)	13.5 (56.3)	70	150.3 (270.5)	0.0 (0.0)
April	41.40 (1.63)	6.00 (1904)	14.7 (58.5)	73	117.4 (211.3)	0.0 (0.0)
May	7.37 (0.29)	5.96 (1890)	16.3 (61.3)	71	74.2 (133.6)	0.9 (1.7)
June	0.51 (0.02)	6.21 (1970)	17.9 (64.3)	73	36.1 (64.9)	0.6 (1.1)
July	0.25 (0.01)	6.82 (2163)	21.0 (69.8)	73	3.0 (5.4)	5.9 (10.7)
August	1.02 (0.04)	6.37 (2020)	22.2 (72.0)	75	0.1 (0.1)	9.2 (16.6)
September	2.54 (0.10)	5.03 (1595)	20.0 (68.0)	72	9.3 (16.7)	6.4 (11.6)
October	6.60 (0.26)	4.00 (1267)	18.5 (65.3)	71	35.1 (63.2)	5.7 (10.2)
November	25.65 (1.01)	2.66 (844)	15.3 (59.5)	62	99.6 (179.2)	0.5 (0.9)
December	42.93 (1.69)	2.34 (743)	11.8 (53.3)	73	202.4 (364.3)	0.0 (0.0)
Annual	325.12 (12.80)	4.66 (1477)	16.4 (61.5)	71	1078.6 (1941.5)	29.2 (52.6)

2. Location

The pilot plant and The Timbers are at 34° N latitude and 118° W longitude, approximately 95 km (60 miles) apart. The pilot plant is 335 m (1100 ft) above sea level, nestled at the southern foot of the San Gabriel mountains which rise to 2000 m (6500 feet) in height. The Pacific Ocean lies approximately 60 miles to the southwest.

The Timbers is 32 m (100 ft) above sea level and 20 km (12 miles) east of the Pacific Ocean. It is in the middle of the inland valley of the Los Angeles Basin, equidistant to the ocean on the west and the Santa Ana Mountains on the east, 1700 m (5500 ft) in height.

3. Solar Radiation

Total annual insolation in El Toro is 1700 kwh/m^2 (536×10^3 Btu/ft^2) and 1820 kwh/m^2 (574×10^3 Btu/ft^2) in Burbank/Pasadena. This is based on a 10 year reporting period from the National Weather Bureau. In general, the cloud factor in Southern California is 60-70%. There is only a 0.7% probability of a hot day occurring with low isolation (less than 2/3 clear sky conditions) and this is most likely to occur in September.

4. Ambient Temperature

The mean monthly temperatures, relative humidity and heating and cooling degree days are supplied by the National Weather Bureau and JPL Report 5040-2. The degree days are based on 18.3°C (65°F) for heating and 23.9°C (75°F) for cooling.

5. Wind

The winds at El Toro and Burbank/Pasadena are quite different, reflecting the influence of the ocean breezes. While it is calm in Burbank/Pasadena 36% of the time, it is calm only 2% of the time in El Toro. The mean hourly speed at Burbank/Pasadena is 2.6 m/sec (5.0 knots) ranging from a low of 2.1 m/sec (4.1 knots) in the winter to 2.9 m/sec (5.7 knots) in the summer. The wind is predominantly from the south, shifting to the northwest in the winter.

The wind at El Toro is stronger than at Burbank/Pasadena. Fifty-six percent of the time the mean hourly wind speed is 8-18 m/sec (4-10 knots) in the morning, increasing to 86% of the time in the afternoon. The prevailing wind direction is southwest off the ocean, shifting to the northeast in the winter.

II. SYSTEM DESCRIPTION AND THERMAL PERFORMANCE

A. PILOT PLANT – PASADENA, CALIFORNIA

1. Description of the System

Qualitative Description

The pilot plant is located in an existing building at JPL (Fig. 1). The collectors are mounted on the roof with most of the piping, tankage and instrumentation inside. Components of the system include 32 collector panels, a storage tank, tempering tank, heat exchanger, pumps, differential thermostatic controller, conventional gas fired boiler and instrumentation. All of the equipment was purchased off-the-shelf with the exception of the collectors.

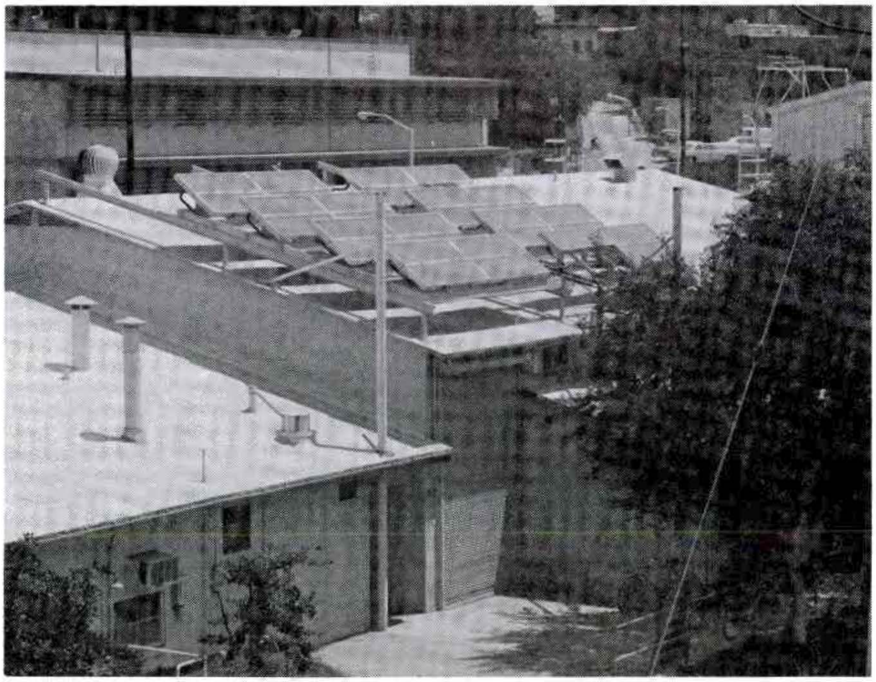


Fig. 1. SAGE Pilot Plant – Pasadena, California

The collectors were designed, built and installed by the engineers at JPL and the technology transferred to a commercial manufacturer who further refined the design for the collectors for The Timbers.

The pilot plant was designed to test various solar water heating system configurations. In order to accomplish this with minimal difficulty, 1) the pilot plant was sized for a 10-unit apartment building; 2) hourly hot water demand (Table 3) was simulated using tables developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); 3) solar insolation was held constant for each configuration to allow comparative performance evaluations of the various systems, and 4) manual gate valves were located throughout the piping system so that the changes could easily be made from one configuration to another. The pilot plant operated in the various configurations over a 6 month period of time.

Quantitative Description

The pilot plant equipment consisted of 32 collector panels for an effective area of 33.6 m^2 (362 ft^2); a 1700 liter (450 gallon) water storage tank; a 284 liter (75 gallon) tempering tank; six heat exchangers in series; a differential thermostatic controller; and a conventional gasfired boiler. The collectors were mounted in modules of four panels in series and eight modules in parallel. They were mounted 6° east of south at an inclination of 53° (Fig. 2).

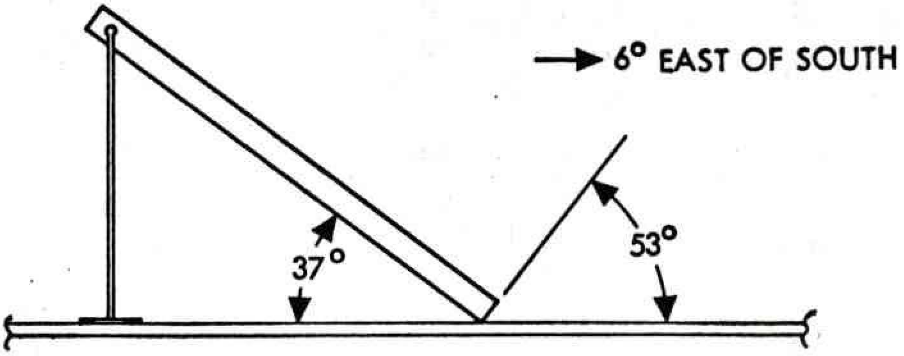


Fig. 2. Orientation and Inclination of Pilot Plant Collectors

Table 3. SAGE Pilot Plant Hot Water Demand Program

Hour	Demand Liter/Demand Event (Gallon/Demand Event) Minutes After the Hour				Liter/Hour (Gallon/Hour)
Hour	0:00	0:15	0:30	0:45	
00:	30.3(8)	15.1(4)	15.1(4)	15.1(4)	75.7(20)
01:	15.1(4)	15.1(4)	7.6(2)	15.1(4)	53.0(14)
02:	7.6(2)	7.6(2)	15.1(4)	0 (0)	30.3(8)
03:	15.1(4)	0 (0)	0 (0)	0 (0)	15.1(4)
04:	7.6(2)	0 (0)	15.1(4)	0 (0)	22.7(6)
05:	0 (0)	0 (0)	7.6(2)	0 (0)	37.8(10)
06:	15.1(4)	15.1(4)	7.6(2)	0 (0)	37.8(10)
07:	15.1(4)	0 (0)	15.1(4)	30.3(8)	60.6(16)
08:	60.6(16)	30.3(8)	60.6(16)	7.6(2)	159.0(42)
09:	60.6(16)	30.3(8)	15.1(4)	15.1(4)	121.1(32)
10:	60.6(16)	30.3(8)	15.1(4)	30.3(8)	136.2(36)
11:	60.6(16)	15.1(4)	30.3(8)	15.1(4)	121.1(32)
12:	30.3(8)	15.1(4)	30.3(8)	30.3(8)	106.0(28)
13:	15.1(4)	30.3(8)	30.3(8)	30.3(8)	106.0(28)
14:	30.3(8)	30.3(8)	15.1(4)	30.3(8)	106.0(28)
15:	30.3(8)	30.3(8)	15.1(4)	7.6(2)	83.3(22)
16:	30.3(8)	7.6(2)	30.3(8)	30.3(8)	98.4(26)
17:	30.3(8)	30.3(8)	15.1(4)	15.1(4)	90.8(24)
18:	15.1(4)	30.3(8)	15.1(4)	30.3(8)	90.8(24)
19:	60.6(16)	30.3(8)	30.3(8)	15.1(4)	136.3(36)
20:	60.6(16)	30.3(8)	60.6(16)	15.1(4)	166.5(44)
21:	30.3(16)	60.6(16)	30.3(8)	30.3(8)	151.4(40)
22:	30.3(16)	30.3(8)	30.3(8)	15.1(4)	106.0(28)
23:	7.6(2)	30.3(8)	15.1(4)	30.3(8)	83.3(22)
Total liter (gal)/day					2195.3(580)

Although numerous configurations were evaluated, only three were examined in detail - Systems SO, SC and SD. All three systems included solar collectors, pumps and a storage tank on the solar collection part of the system as well as a conventional gas boiler, pumps and a tempering tank on the demand side of the system. The tempering tank was used to prevent water exceeding 60°C (140°F) from suddenly arriving at the user's tap. With the possibility of storage tank temperatures in the range of 71°-93°C (160°-200°F) on days when the demand for hot water by residents of the apartment was low, "slugs" of excessively hot water would be drawn into the circulation line. The tempering tank effectively prevents this from occurring.

The three systems can be distinguished as follows: System SO had no heat exchanger, System SC had a heat exchanger on the collector side of the storage tank, and System SD had the heat exchanger on the demand side of the tank.

System SO

SO was the simplest SAGE water heating system. Shown in Fig. 3, it consisted of a conventional circulating loop hot water system to which was added a storage tank in the cold water make-up line and a tempering tank in the circulating loop. The water in the storage tank was heated by being pumped through the solar-collector array. Results showed that, of all the systems tested, the collectors in System SO operated at the lowest temperatures and therefore the highest efficiency. The higher efficiency was produced by the good thermal stratification in the storage tank and the exclusion of a heat exchanger. However, the costs of the tank and collectors were higher than in the other systems because they had to withstand the water pressure from the main.

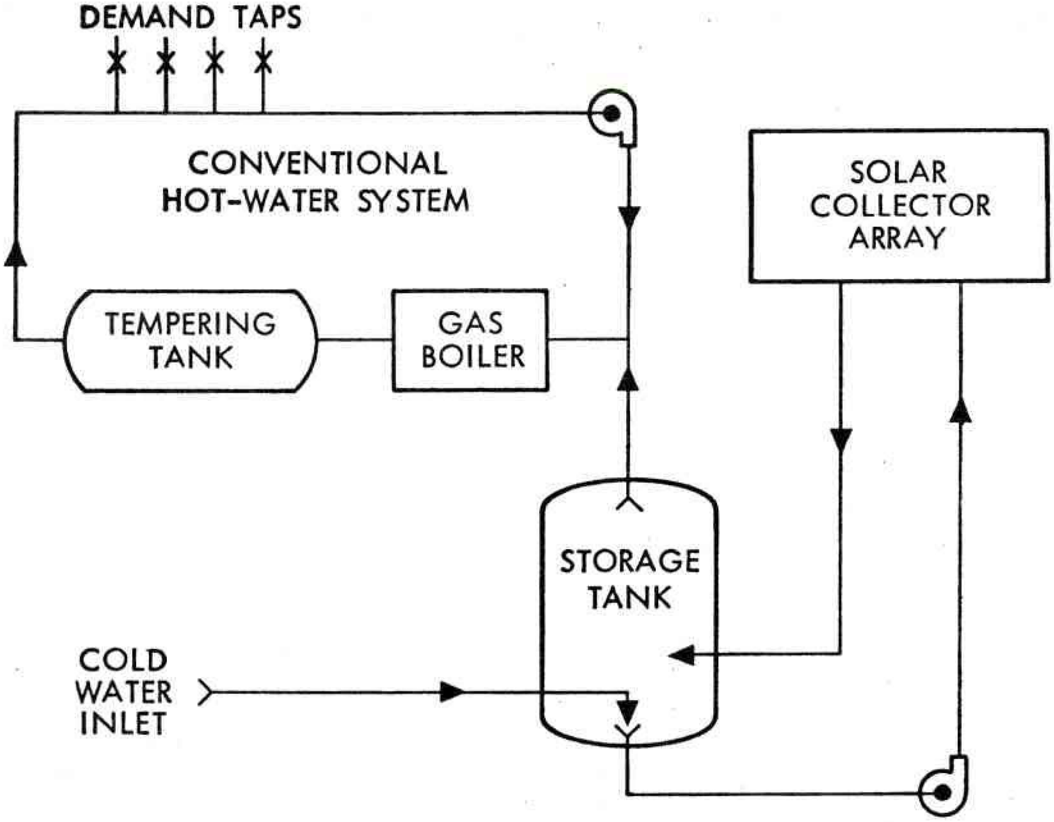


Fig. 3. SAGE Water Heating System SO

System SC

System SC was similar to System SO but had a heat exchanger between the storage tank and the solar collectors as shown in Fig. 4. The storage tank was the same as in System SO and maintained the same thermal stratification. This system was not tested, however, because of its close resemblance to System SO. The only performance difference between the two systems was the temperature drop across the heat exchanger, which would cause the collector to be somewhat warmer and less efficient.

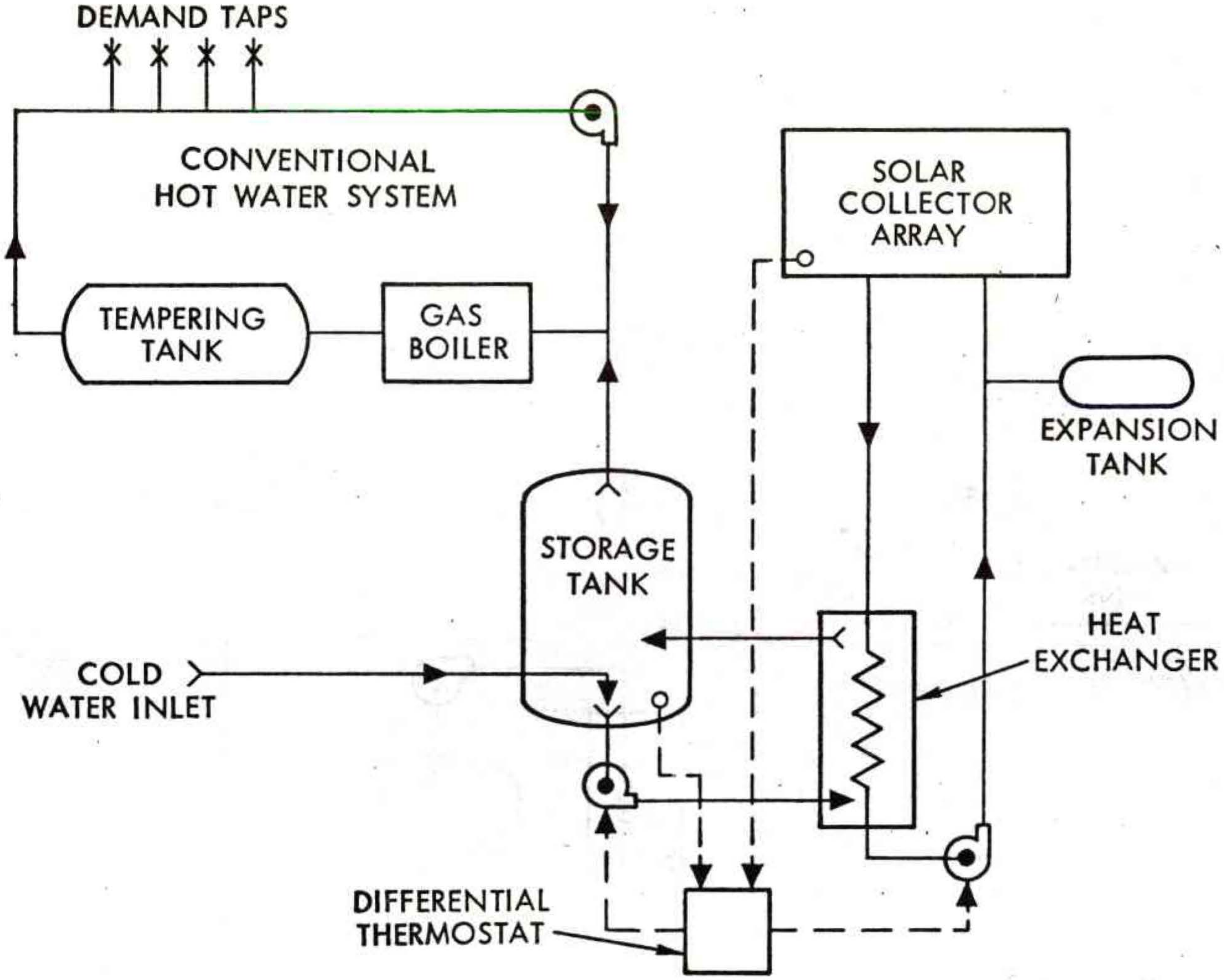


Fig. 4. SAGE Water Heater System SC

System SD

System SD had a heat exchanger between the storage tank and the conventional hot water system as shown in Fig. 5. This allowed the tank and collectors to operate at low pressure since water from the main entered at the heat exchanger. In terms of the collector area required to yield a given fuel saving, System SD was less efficient than either System SO or SC primarily because of the temperature drop across the heat exchanger and the fact that the tank was thermally mixed instead of stratified.

A differential thermostatic controller operated the two pumps used to circulate water through the collectors. Temperature sensors were located at the outlet from the last panel in the collector array and the top of the storage tank. The pumps turned on when the difference between the tank and the collectors reached 11.1°C (20°F) and turned off when the difference dropped to 1.6°C (3°F).

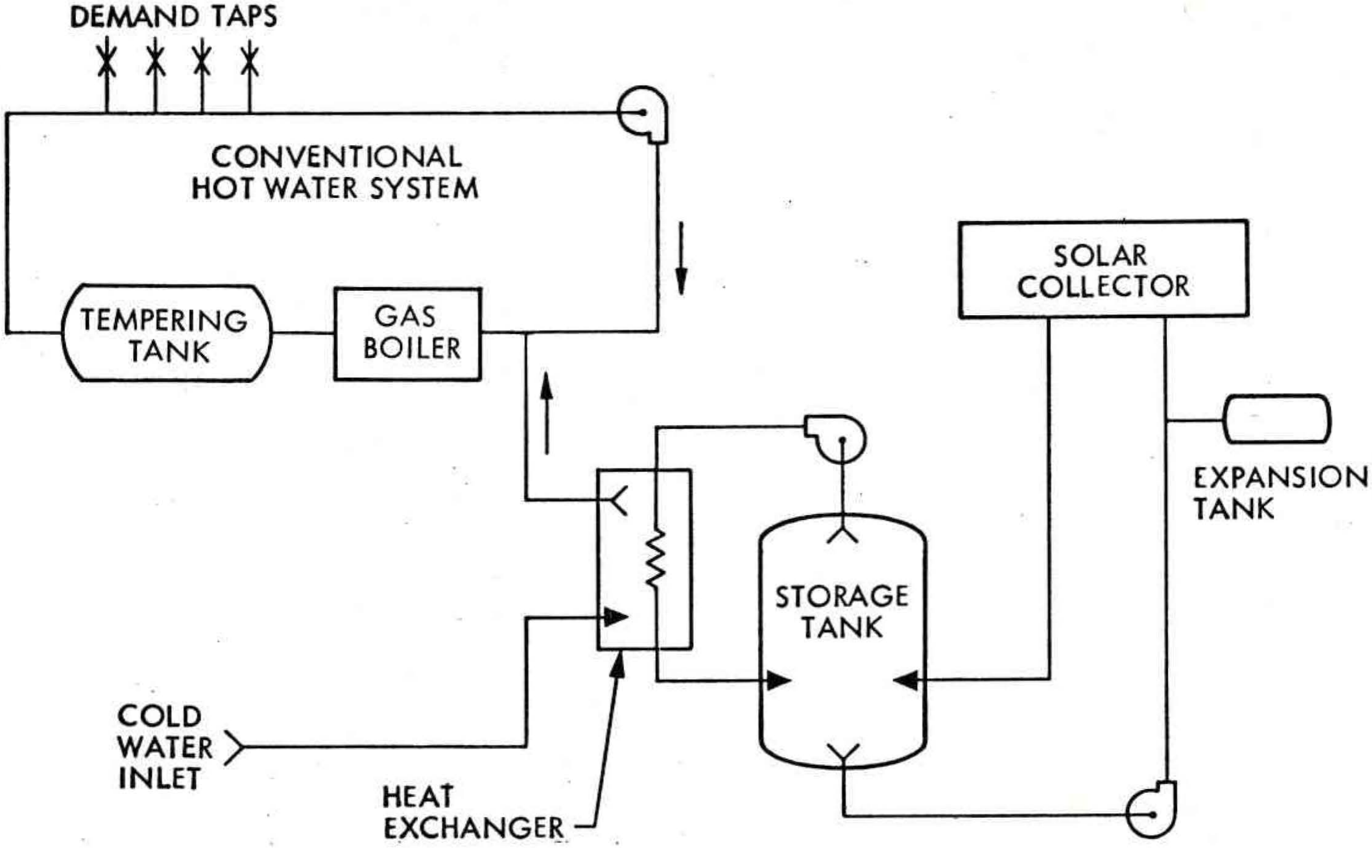


Fig. 5. SAGE Water Heating System SD

2. System Thermal Performance

Because of the numerous configurations evaluated at the pilot plant only a brief summary of the results will be given in this section. Further details will be found either in the subsystem performance section or JPL Document 5030-15[2].

The overall performance of the SAGE water heating systems at the pilot plant was better than estimated in the computer evaluations: the solar energy input was greater and the solar collectors were more efficient. However, contrary to estimates, the efficiency of the boiler decreased at reduced loads, and a small amount of solar energy was supplied to circulating line losses.

The central water heating budget, Table 4, describes the performance of SAGE water heating vs. conventional gas water heating. The data from the pilot plant was scaled to a 32-unit apartment building and was also used to size all three systems, SO, SD and SC. The most efficient system was System SO and it was sized at 120.7 m^2 (1300 ft^2). To provide the equivalent performance, System SC was sized at 131.9 m^2 (1420 ft^2) and System SD was sized at 139.4 m^2 (1500 ft^2). As designed these systems would supply 85% of the demand with an overall system efficiency of 52%. Comparison of this energy budget with an actual installation is discussed in The Timbers thermal performance evaluation (section II-B).

Figure 6 is a chart of solar energy incident and solar energy collected that was developed from extensive evaluations in June and July 1974. The insolation measured normal to the solar collectors and integrated between 08:00 and 17:00 varied from 4.76 kwh/m^2 (1510 Btu/ft^2) to 5.67 kwh/m^2 (1800 Btu/ft^2). The low values were due to morning clouds and fog which typically cleared before 10:00. The insolation integrated over the maximum hour at mid-day varied much less: 0.81 to 0.83 kwh/m^2 (256 to 263 Btu/ft^2). The annual solar ratio of energy was calculated from annual to July solar energy input of 0.89. With an average daily collector efficiency of 52%, the annual average solar energy input into the system was 2.33 kwh/day per m^2 (740 Btu/day per ft^2) or 851 kwh/year per m^2 (0.27×10^6 Btu/year per ft^2).

Table 4. Central Water Heating Energy Budgets

Energy	System Tape			
From	SAGE			Conventional
To	Sun	Gas	Total	Gas
Demand	277 (945)	85 (290)	362 (1235)	362 (1235)
Tank Loss	11.7 (40)	--	11.7 (40)	--
Loop Loss	17.6 (60)	73.2 (250)	90.8 (310)	90.8 (310)
Boiler Loss	--	107 (365)	107 (365)	173 (590)
Pilot Light	--	14.6 (50)	14.6 (50)	14.6 (50)
Total	306 (1045)	280 (955)	586 (2000)	640 (2185)

NOTES:

1. Units: kwh (10^3 Btu)/day/32-unit apartment building.
2. Pilot plant test data scaled to a 32-unit apartment.
3. Based on demand: 220 liters (58 gal)/day/unit at 44°C (80°F) rise.
4. Collector area: SO - 121.7 m^2 (1300 ft^2)
   SC - 131.9 m^2 (1420 ft^2)
   SD - 139.4 m^2 (1500 ft^2)
5. Results for a day averaged over 12 months.

From data received during this same July 1974 testing, the amount of natural gas fuel saved was 3.37 kwh/day per m^2 (1070 Btu/day per ft^2) for System SO (no heat exchanger) or 1.29 times the solar input. This fuel savings was larger than the solar input because the boiler efficiency was less than 100%.

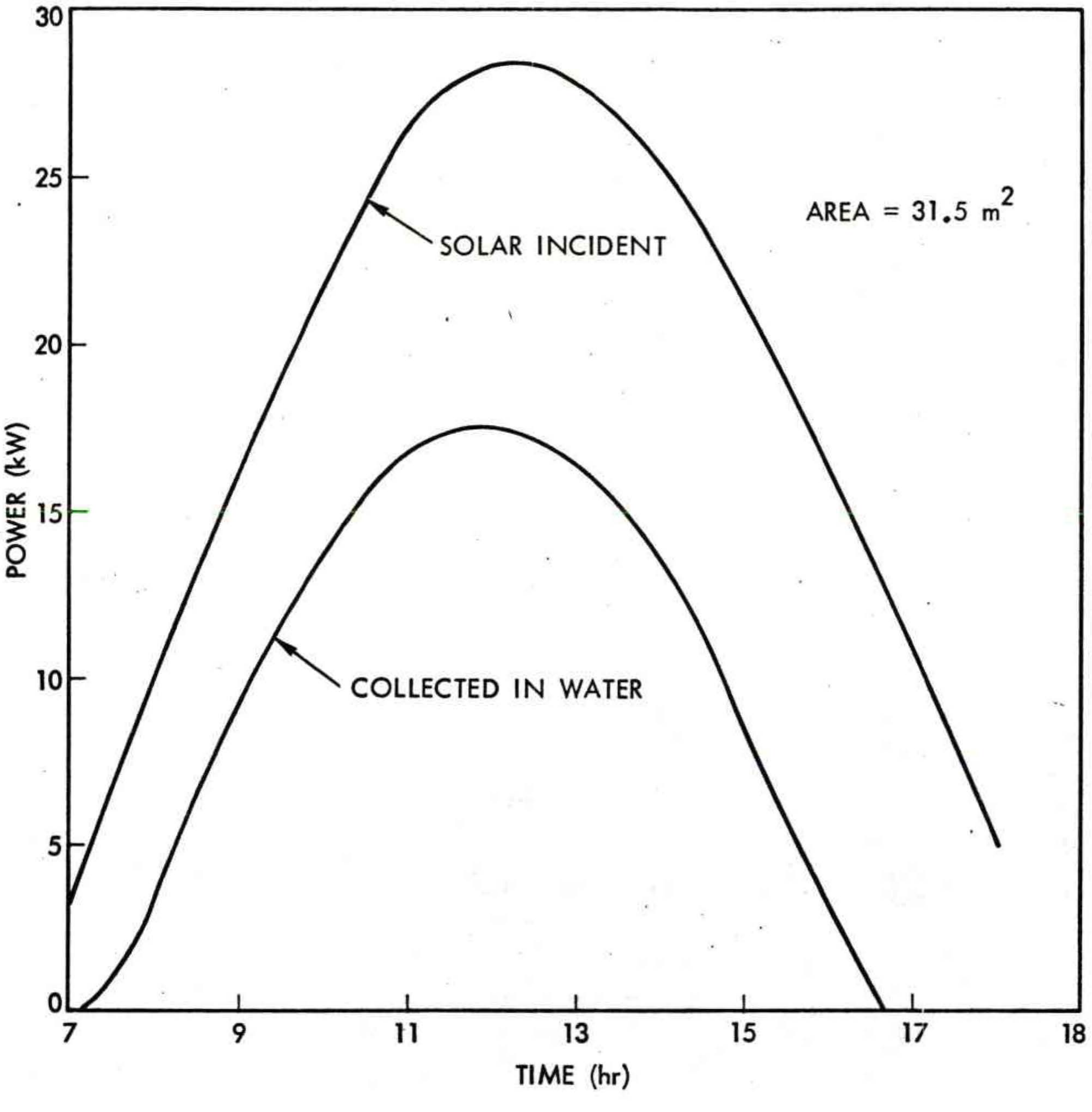


Fig. 6. Solar Incident and Collected Power — SAGE Pilot Plant

The pilot plant data, averaged over the testing period, are given in the heat flow diagram in Fig. 7.

System SO (no heat exchanger) and System SD (heat exchanger in demand side of tank) are given along with the heat flows for a conventional (no solar input) system. System SC was not evaluated because of its similarity to System SO. All the numbers are in kwh/day (10^3 Btu/day).

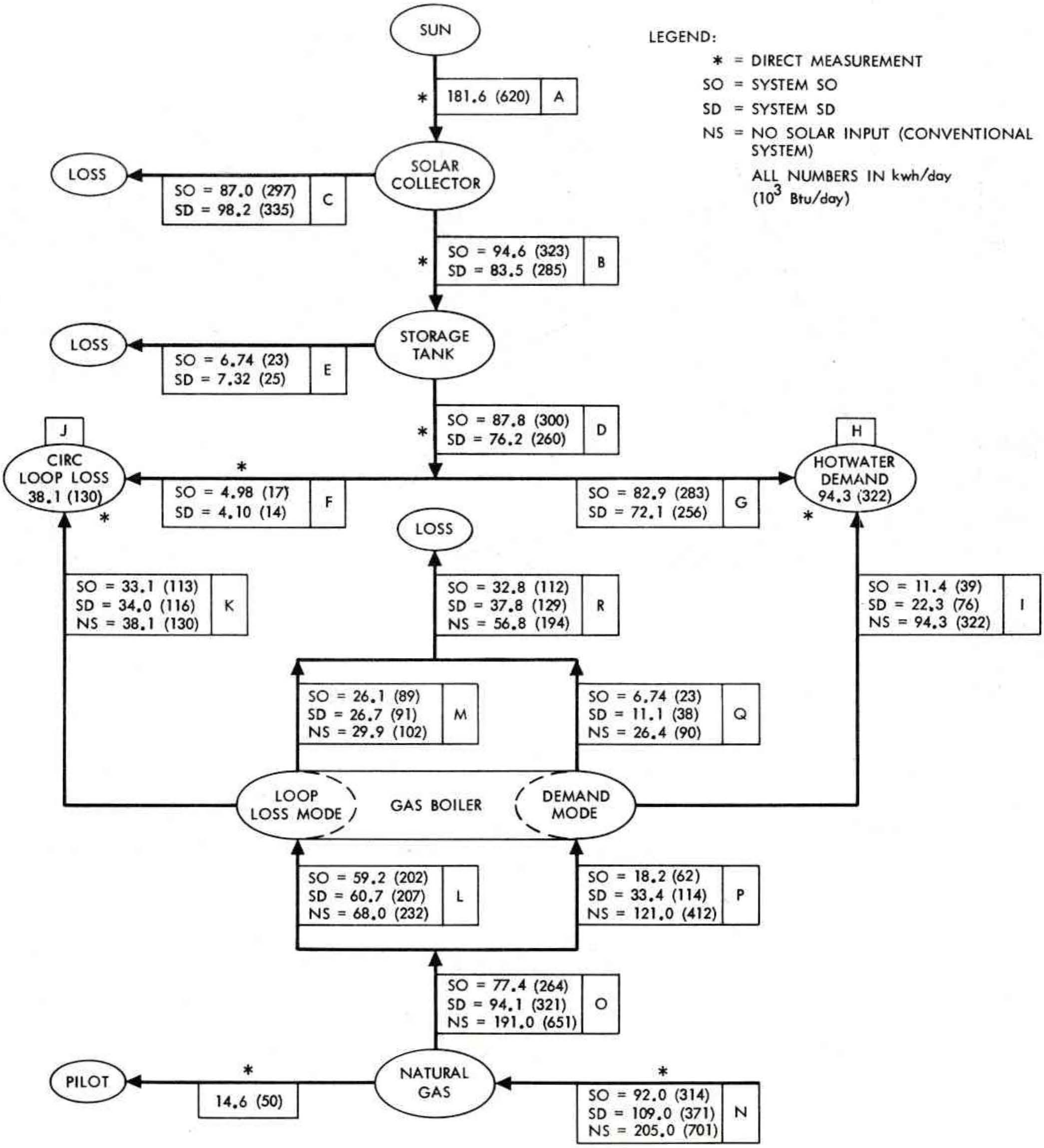


Fig. 7. Average July 1974 Heat Flows in SAGE Pilot Plant

The solar input to the collector (block A) is the product of the insolation and the total effective area of the collector array. The heat flow into the storage tank (block B) was found from the product of the water flow rate and temperature rise in the collector integrated over the time that the collector pump was operating. The heat extracted from the tank (block D) was calculated from the total mass of water which flowed at each demand event and the difference between the cold water make-up temperature, 20.6-22.7°C (69-73°F), and the temperature of the water in the loop (i. e., the temperature at the hot water demand taps, 57.2-61.7°C (135-143°F). The excess heat (block F) at each such demand event provided a portion of the circulating loop losses. The total of such heat in a day amounted to only a few percent of the heat extracted from the tank with the balance (block G) used for the demand water. The demand heat required (block H) was found from the mass of water flowed at each demand and the difference between the cold water make-up temperature and the temperature at which water was supplied to the hot water demand taps. The difference between this quantity and the heat extracted from the tank for the demand is the amount required to be supplied from the boiler (block I). The heat lost in the circulating loop (block J) is a function of the loop and the ambient air temperatures. This relationship was determined separately and used to calculate the heat loss each day. The heat required for this purpose from the boiler (block K) is the total loop loss, less the heat extracted from the tank for the loop loss. When the boiler is operating at the low output level necessary to supply the loop losses, it is at its minimum efficiency (56%), and the natural gas usage (block L) is readily calculated. The total gas used is measured (block N), and the difference between that amount (less pilot light, block O) and the amount used for the loop loss is the amount used for the hot water demand (block P).

The boiler efficiency when supplying the demand is calculated from the input (block P) and output (block I) heats. For System SO, this is 64% as compared to 78% for the conventional (i. e., no solar input) system. The lower value is consistent with the fact that when solar energy is used to preheat the cold water make-up, the boiler operates at a lower heating rate and thus at a lower efficiency.

Following the completion of the Phase II study, System SC (heat exchanger in the collector loop) was selected as the system for use in the field test installations at The Timbers and Upland. System SO (no heat exchanger) was the least expensive on a kwh/m^2 basis; however, on a kwh/dollar basis, System SC was the least expensive. The reasons were as follows:

(1) The least expensive materials used to build collectors in the future would be steel or aluminum.

(2) If steel or aluminum were used, inhibitors would be required in the collector loop to prevent corrosion of the collector panels. (This would not be a problem with copper but it was considered to be much too expensive, even in the long run.)

(3) By inserting a heat exchanger in the collector loop, inhibitors could be used in the collector loop without contaminating the potable water.

(4) Given the above reasons, System SC was selected for the field test in order to obtain measured performance data on a system with a heat exchanger in the collector loop. In the pilot plant its performance had only been estimated.

One major modification of the estimated System SC was made in the installed Timbers system - hot water demand was determined to be lower than originally estimated; therefore, the collector area was reduced from 131.9 m^2 (1420 ft^2) to 93.6 m^2 (1008 ft^2). In both cases, however, the collector-area to hot-water-demand ratio remained the same.

B. THE TIMBERS - EL TORO, CALIFORNIA

1. Description of the System

Qualitative Description

The Timbers is a 168-unit, 11-building/complex of which two buildings and 32 units are being used in the field test. The buildings are of two-story, flat-roofed, typical wood frame construction. The 48 collectors are mounted on the roof, divided evenly between the two buildings (Fig. 8).

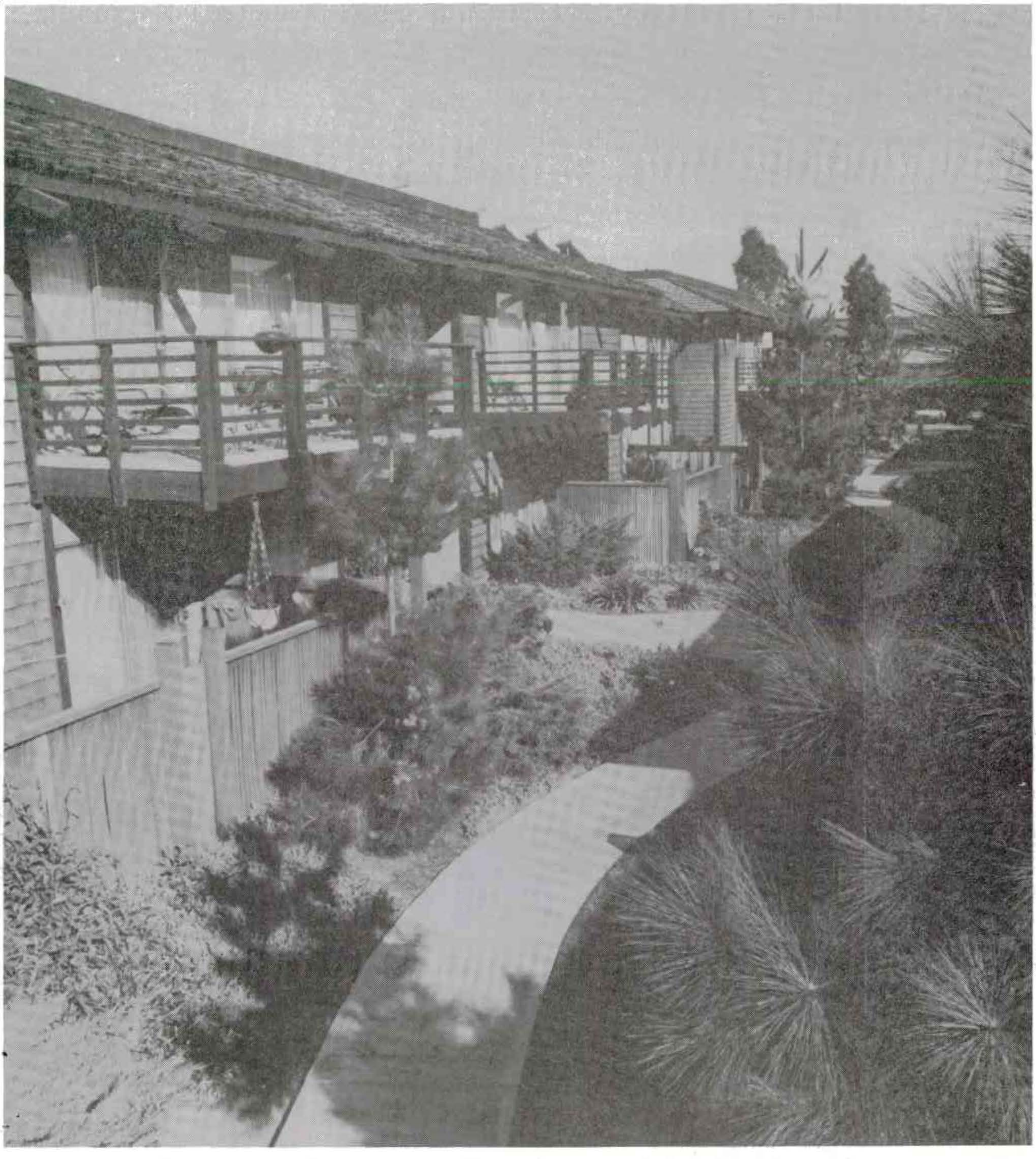


Fig. 8. The Timbers Apartments, El Toro, California

Although the collectors could have been mounted on a single roof, they were divided in order to visually illustrate the collector area required to supply hot water for each building. In addition it helped minimize the visibility of the collectors, thus retaining much of the pre-SAGE environment.

The SAGE water heating system is all copper. Tankage, pumps, heat exchanger and other equipment are tied into a conventional fast-recovery boiler. The equipment is located outdoors in a ground-floor fenced patio. The apartment opening onto the patio houses the data acquisition equipment and also acts as the SAGE information and display area for the general public.

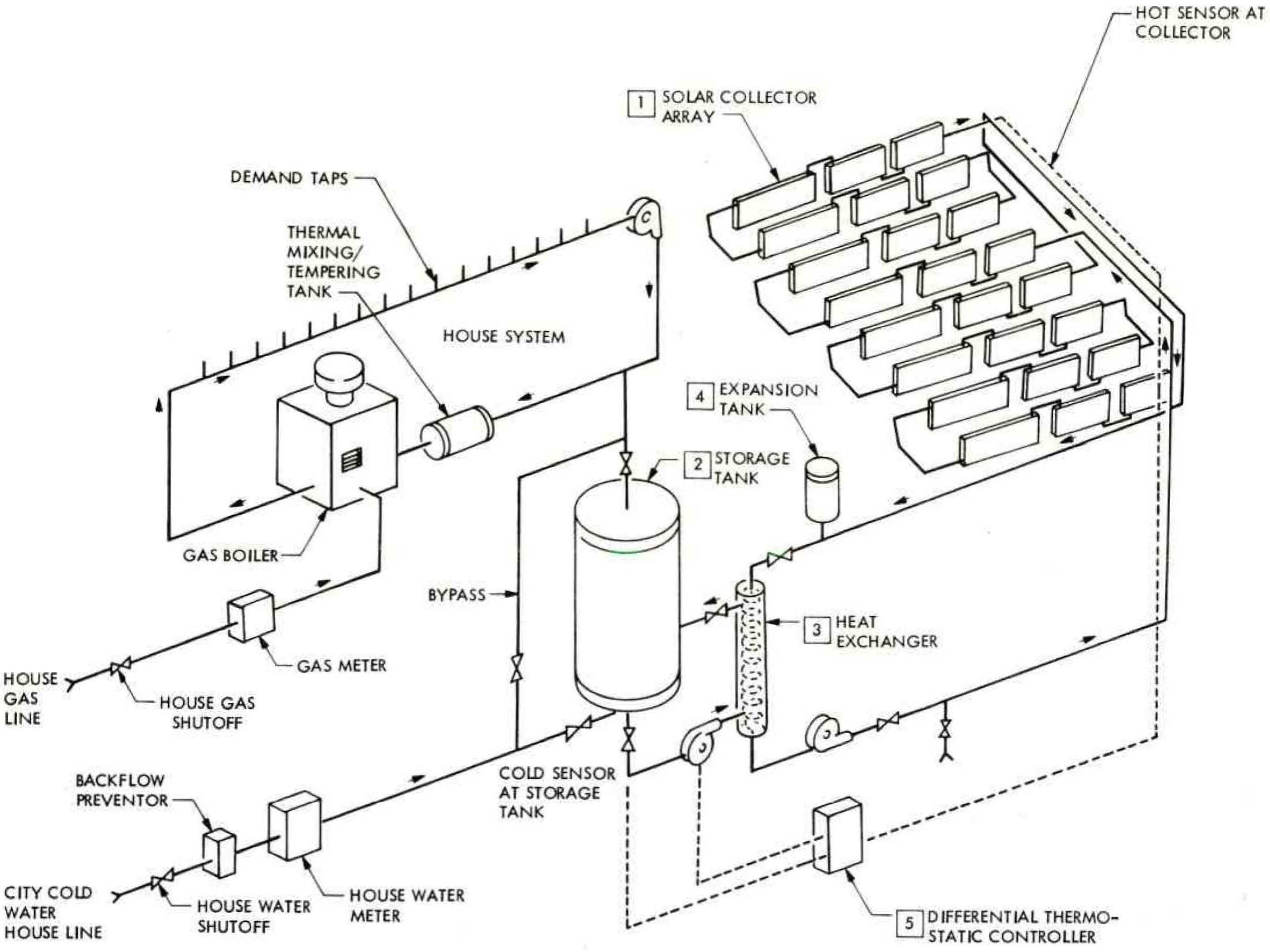
Quantitative Description

The SAGE water heating system at The Timbers was designed as a double-looped system with seven major components: 1) a collector array; 2) a storage tank; 3) a heat exchanger; 4) a differential thermostatic controller; 5) two pumps; 6) an expansion tank; and 7) water with corrosion inhibitors in the collector loop. Because the collector panels are made of copper, regular potable water is used in the loop instead of water with inhibitors. For an all-copper system, in a climate where freezing is not a concern, inhibitors are not considered necessary.

The Timbers SAGE water heating system is shown in Fig. 9 and is used to assist a single loop conventional hydronic system equipped with a fast-firing boiler. In the collector loop there are 48 panels, 24 on each building. Each building has two banks in parallel with 12 panels in each bank in series. Each panel is 1.95 m^2 (21 ft^2) for a total collector array of 93.6 m^2 (1008 ft^2). The collectors are oriented 0° south at an inclination of 53°.

An expansion tank is located on the warm side of the collector loop with a 380 liter (100 gallon) air and a 190 liter (50 gallon) water capacity.

In the second loop of the system cold water make-up enters through the side of the 4620 liter (1220 gallon) storage tank and is directed to the outlet to the heat exchanger at the bottom of the tank. Maximum heat absorptive capacity is then available to pick up heat from the collectors. Water returns to the tank a third of the distance from the bottom of the tank, minimizing cold water mixing in the tank. A differential thermostatic controller activates



No.	Title	Sizing for 40 Unit Apartment	Remarks
1	SOLAR COLLECTORS	48 Panels @ 1.95 m^2 (21 ft^2) ea. = 93.6 m^2 (1008 ft^2) Array	Vertically or Horizontally Mounted in Series-Parallel.
2	STORAGE TANK	1.4 m (4'-6") Diameter x 3.4 m (11'-3") Long = 4620 lit (1220 gal.)	Rated (Pressure and Lining) for Domestic Hot Water Service
3	HEAT EXCHANGER	0.13 m (5") Diameter x 1.8 m (6'-0") Long = 4.75 Kwh -°C (9000 Btu/hr-°F)	Min. 1.6 lit/sec (25 gpm) Flow, Each Side
4	EXPANSION TANK	0.61 m (2'-0") Diameter x 1.6 m (5'-3") Long = 380 lit (100 gal.) Air 570 lit (150 gal.) H_2O	
5	DIFFERENTIAL CONTROLLER	"Rho Sigma" Thermostat Model 102	Set @ 11.6°C (20°F) Turn-On/ 1.6°C (3°F) Turn-Off

Fig. 9. Schematic of Assembled SAGE Solar Pre-Heat System - The Timbers, El Toro, California

circulating pumps when heat can be added to the storage tank with the same parameters as the pilot plant.

Water is drawn from the top of the tank, where the hottest water is available to the demand loop. Because of the possibility of surges of excessively hot water in the demand loop, a 380 liter (100 gallon) tempering tank is placed between the gas boiler and the storage tank. This allows mixing of the overheated water with regular hot water so that only a slight temperature rise occurs in the demand loop.

The Timbers installation is fully instrumented and the sensor locations are shown in Fig. 10. There are 14 temperature sensors, three flowmeters and three weather sensors providing data for the data acquisition system. They are listed in Table 5.

Flowmeters: Two types of flowmeters are used - two with a range of 2.5-30 gpm and one more sensitive for accurately recording the demand with a range of 0.03-25 gpm.

Temperature Sensors: Fifteen platinum resistance temperature sensors have an accuracy of ±0.1°C (±1°F) over a temperature range of 0.5°C (33°F) to 100°C (212°F).

Insolation: Insolation measurements are taken with an Eppley 8-48 Pyranometer or equivalent. Accuracy is ±2% or better.

Wind: Wind measurements of 1 to 90 mph are taken with an accuracy of ±5% with an anemometer installed on the site.

Ambient Temperature: Ambient temperature is measured over the range of -17.7°C (0°F) to 65.5° (150°F) to an accuracy of ±0.28°C (±0.5°F). The sensor is mounted under the solar collector in a convective air aspirator, designed to block light and rainfall.

The data acquisition system, manufactured by Data Works, Inc. specifically for SAGE, collects, processes, displays and stores the information on magnetic tape (IBM format) for mass storage. Sampling of all the sensors, or intermediate storage buffers in the case of the flowmeters, is once per

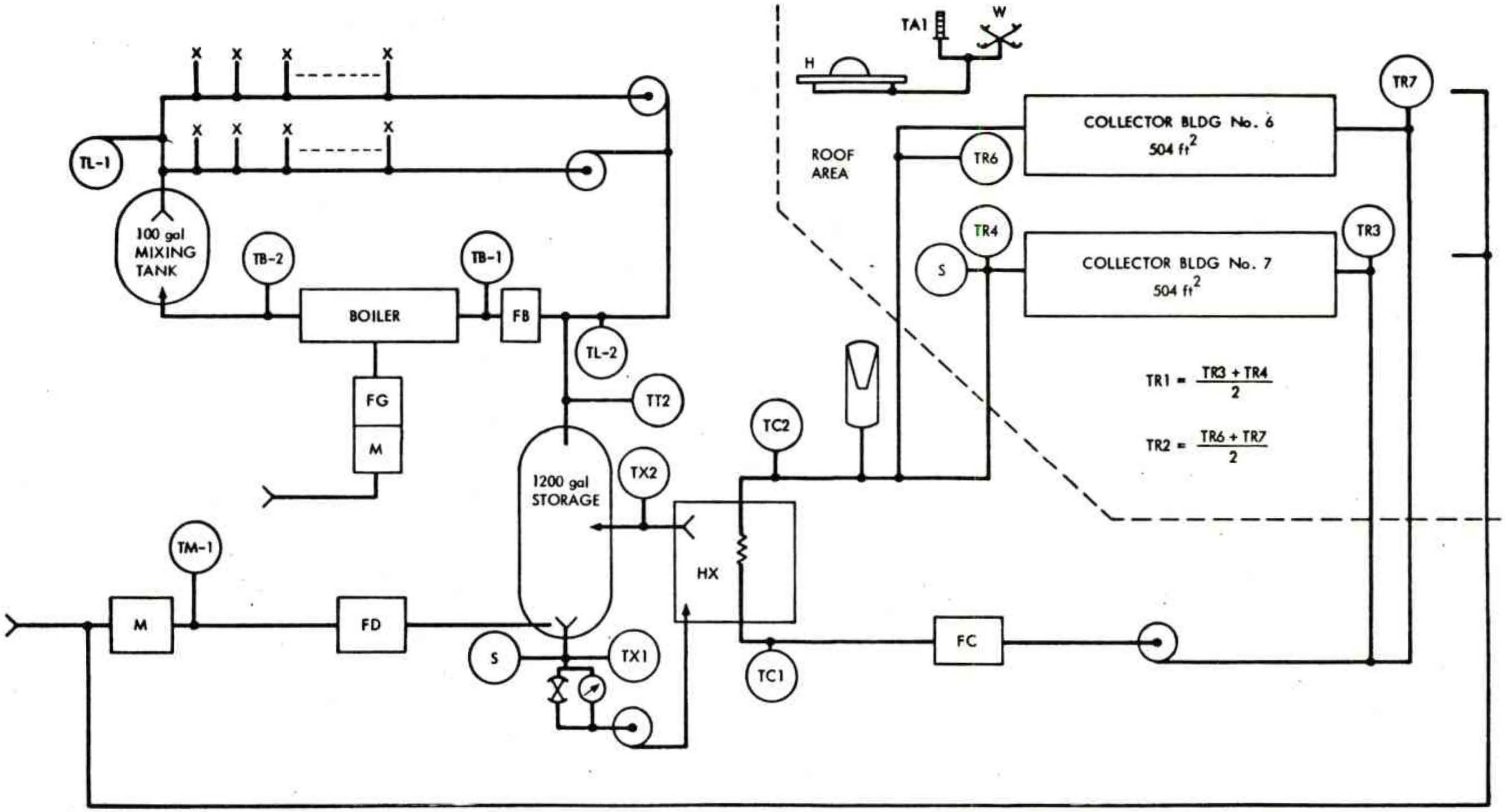


Fig. 10. SAGE Sensor Locations - The Timbers, El Toro, California

Table 5. Instrumentation Symbol List

Temperature Sensors

TM1 - Make-up Water
TX1 - Input to Heat Exchanger
TX2 - Output from Heat Exchanger
TC1 - Input to Collectors at Heat Exchanger
TC2 - Return from Collectors at Heat Exchanger
TR3 - Input to Collectors on Building No. 7
TR4 - Output from Collectors on Building No. 7
TR7 - Input to Collectors on Building No. 6
TR6 - Output from Collectors on Building No. 6
TT2 - Output from Storage Tank
TL2 - Loop End Temperature
TL1 - Loop Start Temperature
TB1 - Input to Boiler
TB2 - Exit from Boiler

Flowmeters

FD - Make-up Water
FC - Collector Loop
FB - Boiler Flow

Weather Sensors

W - Wind
TA - Ambient Temperature
H - Insolation

second and also averaged over a one minute period. Each minute the heat calculations and efficiencies in Table 6 are calculated with running cumulatives of QS, QC, QD, MD, FD, QTI and QTO maintained for a 24 hour period.

In addition to the one minute recording of the data, 15 minute summaries (averages) are calculated and placed on tape. Hard copy printout is normally done for 15 minute resolutions; however, it will also print out the one minute resolution on request. Table 7 is an example of the output of the data acquisition system.

2. System Thermal Performance

The SAGE water heating system at The Timbers began operation in August 1975. Because of continuing problems with the data acquisition system, measured data is available only for parts of May and June 1976. Debugging of the data acquisition system is still in progress; therefore, the following information is only a preliminary evaluation of the system's thermal performance.

a. Daily, Monthly and Annual Values of the Mean Daily Energies. The monthly and annual summaries of the mean daily energies are given in Table 8. These are based on the measured daily values in Table 9 and where necessary corrected according to 10 year weather bureau data to arrive at the projected annual figures.

b. Record of the Quality of the Thermal Performance of the System. Table 10 is a list of various parameters giving the performance of The Timbers SAGE installation as estimated and as measured. From the table it can be seen that the collected energy per square foot of collector is only 76% of the predicted value. This occurred for the following reasons:

(1) The solar energy incident on the collectors was 6% less than expected. It is not certain that this number will remain the same after a full year's data is obtained, but it is the value when the limited data now available is projected.

Table 6. Real Time Calculations

Symbol	Calculated From*	Calculation Frequency	Description
QS	H	Second	Incident solar energy
QC	FC(TR2-TR1)**	Minute	Collected solar energy
EFC	QC/QS	Minute	Collector efficiency
QTI	FC(TC2-TC1)	Minute	Solar energy into tank
QTO	FD(TT2-TH1)	Second	Demand heat out of tank
QD	FD(TL1-TH1)	Second	Total demand heat
QBO	FB(TB2-TB1)	Second	Boiler output heat
QBI	FG	Minute	Boiler input
EFB	QBO/QBI	Minute	Boiler efficiency
QLL	QBO-(QD-QTO)	Minute	Loop loss heat
X	$\left(\frac{TR1 + TR2}{2} - TA\right)/H$	Minute	Normalizing flow parameter for efficiency curve
MD	FD	Minute	Make-up water demand
TR	(TR1 + TR2)/2	Minute	Average collector temperature
DTR	(TR4-TR3 + TR6-TR7)/2	Minute	Temperature rise across collector
DTC	$TC_2 - TC_1$	Minute	Temperature rise across heat exchanger

*Does not include constants or linearization functions.

**TR1 = (TR3 + TR4)/2 TR2 = (TR7 + TR6)/2

Table 7. Example of Data Acquisition System Output - The Timbers, El Toro, California

```
[illegible]
FIELD TEST SITE NO. 1  (THE TIMBERS, EL TORO, CA.)

DATE  02-16-76              TIME  10 15

                               TEMPERATURES (DEG F)
 TM1     TK1     TK2     TT2     TL2     TL1     TE1       TA       TF     DTR     DTC

217.2 119.6 116.7 116.4 117.6 140.9 116.7   65.9 144.1     1.0     7.2
217.0 119.7 116.6 119.0 117.7 140.9 116.6   65.9 142.1     0.0     7.1
217.0 116.7 117.9 119.1 117.5 141.0 116.5   66.0 141.2     0.0     7.1
217.0 119.6 117.7 116.9 117.7 140.9 116.6   66.0 139.5     0.0     6.1
217.5 119.6 117.6 116.4 117.6 140.9 116.5   66.0 140.3     0.0     6.0

217.6 119.5 117.6 116.0 117.6 141.1 116.9   65.9 138.1     0.0     6.1
217.9 119.9 117.9 116.7 117.6 141.1 117.0   65.5 139.1     0.0     6.2
217.9 119.9 116.4 119.1 117.6 141.0 116.9   65.7 137.9     0.0     6.6
216.1 120.0 116.6 116.6 117.9 141.5 117.0   65.5 136.6     0.0     6.7
216.1 120.3 116.6 116.9 117.9 141.5 116.9   65.0 139.9     0.0     6.0

216.1 120.2 116.6 116.9 117.9 141.6 117.1  .65.3 141.0     0.0     6.4
216.2 120.3 116.7 116.6 116.0 141.7 117.0   65.4 142.0     0.0     6.2
216.2 120.3 116.7 116.4 116.0 141.6 117.2   65.4 141.9     0.0     6.1
216.2 120.1 116.9 119.0 116.0 141.7 117.2   65.4 141.7     0.0     6.1
216.2 119.9 120.3 119.9 116.1 141.9 117.2   65.3 143.5     0.0     6.0

217.6 119.9 116.5 116.8 117.9 141.3 117.0   65.7 141.0     0.0     6.5



                      HEATS (BTU)                            (GAL)
   QS        QTI       QTO        QD        QEI       QBO     MD       EFC     EFB

   2574      1509         0         0         0       101    0.2    0.000  0.000  0.311
   2376      1440         0         0         0        51    0.4    0.000  0.000  0.342
   2556      1443         0         0         0       259    0.6    0.000  0.000  0.437
   2254      1292         0         0         0         0    0.0    0.000  0.000  0.503
   2611      1226         0         0         0         0    0.0    0.000  0.000  0.475

   2536      1256         0         0         0         0    0.0    0.000  0.000  0.474
   2520      1272         0         0         0         0    0.2    0.000  0.000  0.463
   2456      1340         0         0         0         0    0.1    0.000  0.000  0.453
   2525      1360         0         0         0         0    0.0    0.000  0.000  0.462
   2270      1333         0         0         0        35    0.6    0.000  0.000  0.556

   2435      1313         0         0         0         0    0.0    0.000  0.000  0.322
   2328      1267         0         0         0         0    0.0    0.000  0.000  0.505
  .2545      1251         0         0         0        36    0.0    0.000  0.000  0.431
   2696      1251         0         0         0       250    0.7    0.000  0.000  0.477
   2564      1333         0         0         0        53    0.3    0.000  0.000  0.320

  37551     19916         0         0         0       787    2.7    0.000  0.000  0.506

 505593    629539         0         0      2100    131604    631 <-- SINCE MIDNIGHT
```

Table 8. Daily and Annual Values of the Mean Daily Energies - The Timbers, El Toro, California

	Hot Water Demand	Supplemental Energy	Solar Energy Incident	Solar Energy Collected	Solar Energy Used	Fuel Savings	Solar Contrib. to Energy Reqts. %
	kwh (Btu × 10^6)						
Measured Daily Mean May-June 1976	179 (0.612)	395 (1.35)	375 (1.28)	148 (0.507)	135 (0.462)	202 (0.689)	75
Projected Annual Mean Daily	178 (0.608)	420 (1.43)	409 (1.40)	164 (0.56)	148 (0.51)	222 (0.756)	83
Projected Annual Total (10^6)	0.065 (222)	0.153 (523)	0.149 (508)	0.060 (204)	0.054 (184)	0.081 (276)	83

Table 9. Measured Daily Values - The Timbers, El Toro, California

Date 1976	Total Hot Water Demand	Supplemental Energy Req'd	Solar Energy Incident	Solar Energy Collected	Solar Energy Used	Fuel Savings	Solar Contrib. to Energy Reqts. %
	kwh (Btu × 10^3)						
May							
4	209 (714)	488 (1670)	393 (1346)	156 (534)	104 (357)	155 (529)	50
5	167 (572)	469 (1600)	321 (1099)	103 (353)	91 (313)	136 (464)	55
6	147 (505)	483 (1650)	156 (533)	0 0	68 (232)	101 (345)	46
7	159 (545)	499 (1710)	440 (1500)	142 (485)	56 (192)	84 (287)	35
8	193 (661)	408 (1390)	285 (974)	122 (417)	152 (521)	227 (775)	79
9	202 (690)	365 (1250)	510 (1740)	200 (684)	185 (633)	276 (942)	92
10	213 (727)	367 (1250)	528 (1810)	195 (667)	194 (665)	291 (993)	91
11	208 (711)	367 (1260)	489 (1670)	144 (491)	185 (633)	276 (942)	89
13	180 (617)	325 (1110)	565 (1930)	199 (682)	190 (651)	284 (969)	106
14	167 (572)	344 (1180)	553 (1890)	186 (636)	171 (583)	255 (870)	102
15	179 (612)	371 (1270)	467 (1600)	170 (580)	165 (566)	246 (840)	93
16	167 (571)	370 (1260)	528 (1810)	214 (732)	155 (529)	231 (788)	92
30	191 (654)	483 (1650)	129 (441)	71 (242)	33 (113)	49 (167)	17
31	203 (696)	403 (1380)	424 (1450)	195 (666)	130 (443)	194 (662)	64
June							
1	174 (595)	348 (1190)	422 (1450)	231 (790)	164 (560)	245 (836)	
2	177 (605)	399 (1370)	155 (531)	65 (221)	129 (441)	193 (659)	73
3	158 (542)	413 (1410)	200 (686)	106 (363)	100 (343)	149 (509)	63
4	144 (492)	376 (1280)	402 (1380)	228 (780)	113 (386)	169 (577)	78
5	205 (700)	368 (1260)	409 (1400)	152 (519)	172 (589)	257 (877)	84
6	202 (692)	362 (1240)	395 (1350)	200 (584)	174 (595)	260 (887)	86
7	211 (721)	367 (1250)	422 (1440)	205 (700)	174 (594)	260 (887)	82
8	214 (733)	360 (1230)	392 (1340)	98 (337)	151 (516)	225 (768)	70
9	163 (557)	429 (1470)	58 (198)	16 (54)	88 (300)	131 (447)	54
10	199 (680)	506 (1730)	208 (712)	92 (315)	69 (236)	103 (352)	35
11	134 (457)	436 (1490)	356 (1220)	150 (513)	77 (262)	115 (392)	57
12	158 (541)	376 (1290)	459 (1570)	187 (639)	140 (480)	209 (713)	89
13	168 (573)	349 (1190)	454 (1550)	163 (558)	165 (563)	246 (840)	98
14	129 (440)	335 (1150)	423 (1450)	152 (521)	134 (459)	200 (683)	104
15	168 (575)	299 (1020)	458 (1570)	160 (546)	188 (643)	281 (956)	112

Table 10. SAGE Water Heating System Comparisons
(Annual Mean Daily Values)

	Estimate		Actual
	Pilot Plant (System SC)	Timbers Installed	Timbers Installed
Collector Area m^2 (ft^2)	131.9 (1420)	93.6 (1008)	93.6 (1008)
Demand liters (gallons)	6990 (1850)	4850 (1280)	3980 (1050)
Demand kwh (Btu × 10^3)	360 (1230)	249 (850)	179 (610)
Area to Demand Ratio m^2/liter (ft^2/gallon)	0.0189 (0.77)	0.0192 (0.79)	0.0235 (0.96)
Energy Collected kwh/m^2 (Btu/ft^2)	2.33 (740)	2.29 (725)	1.77 (560)
Energy Incident kwh/m^2 (Btu/ft^2)	4.79 (1520)	4.70 (1490)	4.42 (1400)
Energy Collected to Demand (%)	0.85	0.85	0.92
Energy Collected to Energy Incident (%)	0.49	0.49	0.40
Fuel Savings kwh/m^2 (Btu/ft^2)	2.73 (865)	2.68 (850)	2.37 (750)

(2) There was about twice as much pipe between the collectors and the storage tank as planned. This reduced the amount of heat actually put into the storage tank by 5%.

(3) The total heat required by the hot water demand was only 72% of the expected heating requirement. This caused the average storage and collector temperatures to be significantly higher than planned, thereby reducing the efficiency of the system by 15%.

c. Supplemental Fuel Use and Annual Fuel Savings. The amount of natural gas supplied to the boiler daily is 395 kwh (135×10^6 Btu). It is greater than anticipated because of some very large circulating line losses in the demand loop. The exact reasons for or location of these losses is still under investigation. Annual fuel savings are 81×10^3 kwh (276×10^6 Btu) per year, which is 88% of the expected energy demand.

d. Heat Flows and Mass Balances. The heat balance diagram for The Timbers is given in Fig. 11. Based on the May-June mean daily values from Table 8, solar energy incident on the collectors was 375 kwh (1.28×10^6 Btu) per day and supplemental gas supplied was 395 kwh (1.35×10^6 Btu) per day. The heat flow through the system is the same as described in the previous heat balance diagram for the pilot plant (Fig. 7).

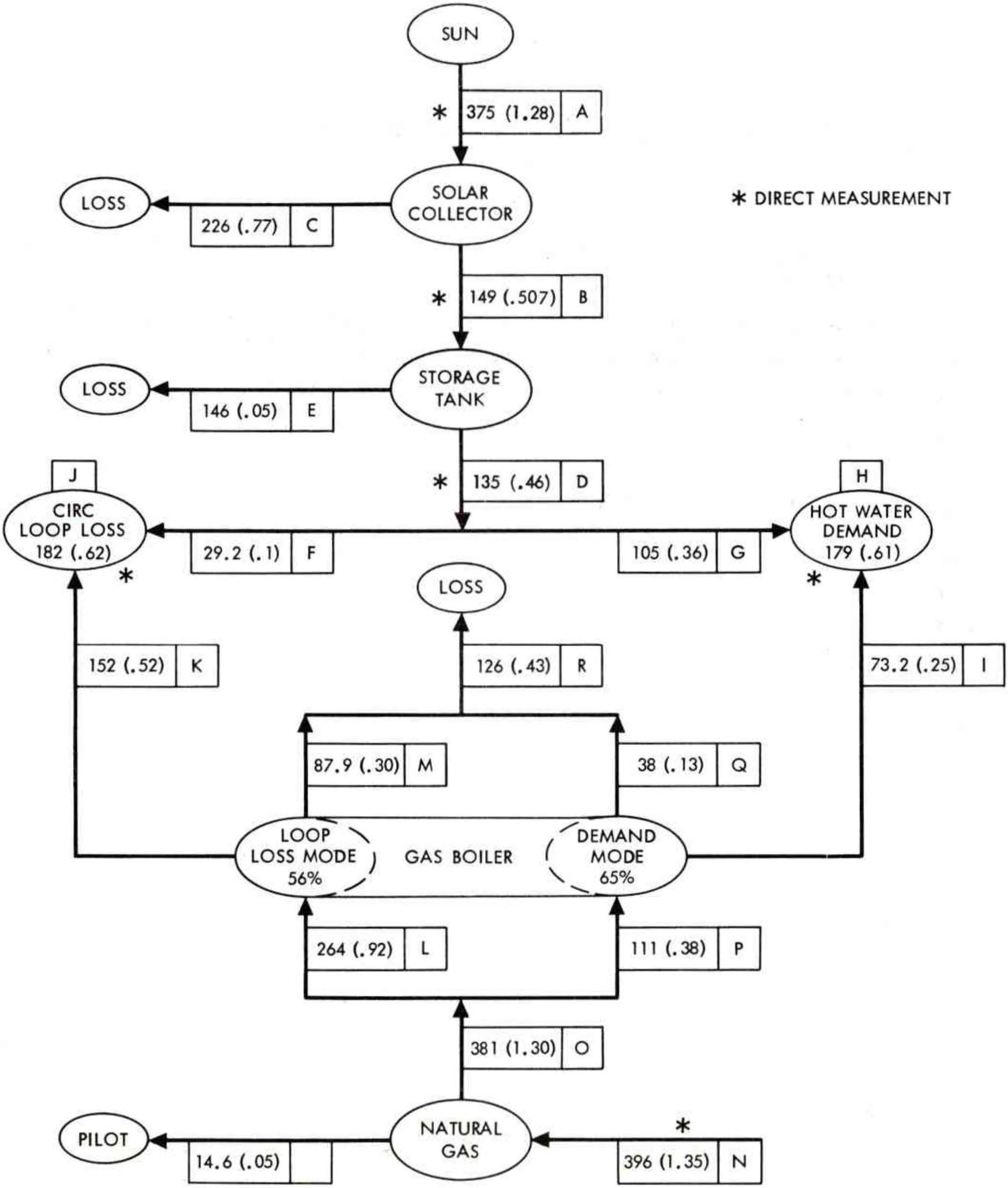


Fig. 11. Average May-June 1976 Heat Flows – The Timbers, El Toro, California

III. SYSTEM ECONOMIC ANALYSIS

A major Phase III objective is a cost comparison of a SAGE water heating installation on a new apartment building and on an existing one. The following economic analysis will describe the estimated costs for various SAGE water heating system configurations established in Phase II, as well as the actual costs from The Timbers and Upland. Although not in operation, Upland is near completion; therefore, estimated costs are available and are included in the following analysis.

A. TOTAL COST OF THE SOLAR PORTION OF THE SYSTEM

Consistent with the overall objectives of the project, SAGE was installed as a part of the normal construction process using conventional industry practices. The developer contracted to GASCO with a conventional plumbing installer as a subcontractor to the developer. All costs were monitored and a time plus materials accounting was required.

Table 11 lists the total cost of The Timbers installation (existing) plus the actual and estimated costs for Upland (new). Previous analyses indicated that retrofits were normally 25-35 percent higher than new installations. In this situation, The Timbers was 59 percent greater than Upland. The Timbers was the first commercial installation of the system and there was a great deal of job learning and on-site modifications; therefore, the installation costs were expected to be higher than for the standard retrofit installation in the future. Because the same developer was in charge of both projects, the experience gained at The Timbers was readily transferable to Upland. Cost reductions on the Upland project produced by the experience on The Timbers installation were readily seen.

Table 11. Total System Costs: SAGE water heating

Collectors	The Timbers (actual)		Upland (estimate)
Panels	$10,900		
Labor	1,570		
Mounting equipment	200		
		12,670	13,500
Tankage			
Vessels	3,200		
Insulation	1,490		
Labor	900		
		5,590	2,900
Heat Exchanger			
Vessel	770		
Labor	340		
Insulation	90		
		1,200	500
Plumbing			
Pipes, valves, fittings	2,000		
Insulation	1,520		
Labor	2,800		
Controller, pumps, misc.	1,640		
Overhead and profit	7,950		
		16,010	1,800
Design			
Architectural and Engineering		4,800	2,800
Carpentry			
Electric and roof revisions		3,030	2,600
Overhead and Profit		4,460	3,000*
Miscellaneous		1,250	1,200
		49,130	28,300
Non-solar costs		1,230	0
TOTAL SYSTEM COST		47,900	28,300

*Excludes general additional management fee and field supervision fee.

B. LABOR COSTS

At both Upland and The Timbers, plumbing labor cost was $21.09 per hour (including direct union benefits). Labor accounted for $2800 at The Timbers or about 35 percent of the plumbing budget excluding overhead and profit.

C. MATERIAL COSTS

The largest single component cost at The Timbers, El Toro was for the solar collectors at $100/m^2 ($10.80/ft^2) or 22 percent of the total system cost. (The collectors for Upland cost $123/m^2 ($13.20/ft^2.)

On a unit basis, labor charges for pipe installation were $6.86/meter ($2.25/linear foot). Total pipe installation (labor and materials) ran $16.76/meter ($5.50/linear foot) of which $5.70/meter ($1.90/linear foot) was piping materials and $4.11/meter ($1.35/linear foot) was insulation.

Total storage tank cost was $3200 for a 4620 liter (1220 gallon) storage tank, a 284 liter (75 gallon) expansion tank and a 380 liter (100 gallon) tempering tank.

The Timbers heat exchanger was specifically designed for this project and at $770 was almost twice what the same item cost for Upland.

D. ANNUALIZED COSTS

Based on the total system costs as noted in Table 11, the annualized costs for The Timbers (retrofit) and Upland (new) are given in Table 12. Actual, near-term and long-term costs are amortized over 10 years at 15 percent interest, and also over 20 years at 8 percent interest. As is shown, at present electricity rates, The Timbers retrofit is competitive at 8 percent and amortized for 20 years. And in the long-term, it is more competitive. At present gas rates, however, a retrofit is not competitive at either interest rate or amortization period.

For new construction SAGE water heating is competitive with electricity at 8 percent interest and 20 year repayment schedule. Assuming a 15 percent interest rate and a 10 year period, the Upland installation is less expensive than 3.5¢/kwh electric water heating. However, neither system can compete with the low retail natural gas rates.

Table 12. SAGE Annualized Cost Summary

Project	Total System Cost ($)	Interest Rate (%)	Amortization Period (Yrs)	Annualized Cost ($)	Cost ($) Per	
					M Btu	Kwh
Timbers Retrofit Actual Cost	47,900	15 8	10 20	9580 4780	35 18	0.120 0.061
Timbers Retrofit Near-Term Commercialized Cost Estimate	32,700	15 8	10 20	6850 3425	24 12	0.082 0.041
Timbers Retrofit Long-Term Commercialized Cost Estimate	24,200	15 8	10 20	5640 2315	19 8.50	0.058 0.032
Upland New Actual Cost Estimate	28,300	15 8	10 20	5640 2820	19 9.50	0.065 0.032
Upland New Near Term Commercialized Cost Estimate	NA	NA	NA	NA	NA	
Upland New Long-Term Commercialized Cost Estimate	12,300	15 8	10 20		8.5 4.25	0.029 0.015
Electricity (1976)	3.5¢/kwh				10.25	
Natural Gas (1976)	$1.50/MCF 67% efficiency				2.25	

E. EXPECTED SELLING PRICE AND COSTS

In Table 13, costs are given for System SO and SC as estimated in Phase I and II. In addition, actual costs for Upland and The Timbers are given with estimates for their near-term and long-term expected costs.

System SO is the system without the heat exchanger and is included as the simplest and most efficient of the SAGE systems analyzed. System SC (heat exchanger on collector side of storage tank) is the system chosen for installation in the field tests. Costs of Systems SO and SC were for new construction; therefore, System SC long-term cost is considered long-term estimate for the Upland (new) installation.

Table 14 is the calculation of the cost savings which result in the lower near-term and long-term system costs. In the near-term, with no new technology, the total system cost for a retrofit drops to \$32, 700.

Part of the near-term savings can be accounted for in the "cost of education" in installing a new type of system and equipment. Example of specific items which were noted in The Timbers debriefing meeting of all the actors were:

(1) The need to increase the flexibility of the connection between the collector and the piping.

(2) Isometric drawings instead of piping diagrams for use by installers to reduce installation time.

(3) Improvement in sleeper design and layout to reduce installation time of mounting collectors on the roof structure.

Near-term savings involve no new technology. However, savings may also accrue from reduced equipment and materials costs through increased production and improved design.

The long-term cost of the retrofitted SAGE water heating system (Table 15) is based on a trial commercial program (Phase IV) of 5000 buildings and 18, 600 m^2 (200, 000 ft^2) of collectors installed each year, low collector costs through mass production, and the availability of new technology. From the original retrofit cost of \$47, 900 at The Timbers, the long-term cost is \$24, 200; or nearly equivalent to the present cost of a new SAGE system.

Table 13. SAGE Hot Water Systems Cost Summary

System	Pilot Plant Estimates (New Construction)			SAGE Actuals		SAGE Estimates	
				Retrofit	New	Retrofit	Retrofit
	SO (1974)	SC (1974)	SC*** (long term)	Timbers (1976)	Upland* (1976)	Timbers*** (near term)	Timbers** (long term)
Collector Size m (f)	92.9 (1000)	92.9 (1000)	92.9 (1000)	93.6 (1008)	93.6 (1008)	93.6 (1008)	93.6 (1008)
Collector Cost per m (ft)	$92.00 ($10.00)	$62.24 ($6.70)	$18.58 ($2.00)	$102.19 ($11.00)	$122.63 ($13.20)	$70.60 ($7.60)	$27.87 ($3.00)
Working Fluid	Water	Treated Water	Water	Water	Water	Water	Water
Collectors	$18.28	$13.82	$ 5.28	$12.67	$ 13.50	$ 8.63	$ 3.93
Tankage	3.04	3.17	3.17	5.59	2.90	4.69	4.02
Plumbing	2.63	2.95	2.95	16.00	1.80	7.51	7.83
Heat Exchanger	0.00	0.89	0.89	1.20	0.50	1.01	0.80
Design	0.00+	0.00+	0.00+	4.80	2.80	2.50	2.00
Carpentry	0.00+	0.00	0.00	3.03	2.60	2.90	2.50
Overhead and Profit	0.00+	0.00+	0.00+	4.46	3.00	3.36	3.00
Miscellaneous	0.00	0.00	0.00	0.00	1.20	0.0	0.0
Total System Cost ($K)	$24.00	$20.80	$12.3	$47.90	$28.30	$32.70	$24.20

+ +Design and profit estimates included above.

*Based on preliminary cost data.

**With savings estimates discussed above.

***This is the equivalent for Upland long-term costs.
All figures are in constant 1975 dollars.

Table 14. Near-Term Retrofit System Cost

	Savings	Original
Collector cost reduction (30% to \$70.60/m^2 (\$7.60/ft^2))	\$ 3,300	\$10,900
Labor learning curve	2,650	5,600
Reduced insulation	1,000	3,100
Risk Reduction	5,800	13,300
Engineering and Design	2,500	9,500
Total	\$15,250	\$47,900

Table 15. Long-Term Retrofit System Cost

	Savings	Original
Collector cost reduction (Glass collector - \$27.87 m^2 (\$3 ft^2)	\$ 7,900	\$10,900
Labor cost reduction (to 130 hours versus 285 hrs for installation)	3,000	5,600
Insulation reduction	1,000	3,100
Risk reduction (to 25% of \$25K total cost without collectors)	7,000	13,300
Engineering and Design	3,000	5,500
Reduced piping needs	500	2,000
Reduced heat exchanger and tanks	800	3,200
Other	400	4,300
Total	\$23,700	\$47,900

The cost figures are total installed system costs to the owner of the system including financing. There are a number of different business arrangements which would determine how these costs are financed, who pays them, and what is the effect of these different arrangements on the marketability of the system. Three principle arrangements are being analyzed: 1) utility ownership; 2) customer lease; 3) customer ownership. Although the total system costs may not change drastically, the impact on the market penetration can be considerable.

F. MAINTENANCE FREQUENCY

The maintenance of the SAGE water heating system at The Timbers has been minimal, averaging only one man-hour per month.

IV. MARKET ASSESSMENT AND UTILIZATION AND POLICY ANALYSIS

The first part of the Phase III objectives has been discussed in the preceding sections. The following comments will address the progress to date of the other two Phase III objectives: the market assessment and utilization and policy analysis for an evaluation of the potential of full commercialization of SAGE water heating by Southern California Gas Company (GASCO).

Assessment of the marketability of SAGE and its implications for a gas utility are presently being analyzed by GASCO. They are looking at considerations such as preferred ownership arrangements, market plans, and views of regulatory agencies toward this type of utility venture. The size of a trial commercial venture (Phase IV) has been established as a minimum of 5000 apartment buildings with a total collector area of 18,600 m^2 (200,000 ft^2) per year.

The final part of Phase III is utilization and policy analysis. This analysis has three interrelated objectives:

(1) To understand the barriers to the widespread use of SAGE water heating in order to develop utilization requirements which internally will inform and refine SAGE water heating technical characteristics and externally will speed the rate of adoption of these systems in both the GASCO and national marketing areas.

(2) To evaluate the potential energy savings from applications of SAGE water heating in Southern California as well as in other parts of the nation.

(3) To identify policy options which might help speed the utilization of SAGE water heating.

Project SAGE studies of building industry characteristics and The Timbers installation debriefing have together produced a series of industry utilization requirements. These are tasks which the project must perform or attributes which the actual system must possess in order to enhance commercial viability of the SAGE system as marketed to the building industry. They reflect Project SAGE's intention to achieve an effective fit with the existing building industry distribution system — in particular, to utilize traditional means by which the building industry communicates characteristics and capabilities of HVAC systems and subsequently makes decisions as to the selection, specification, and incorporation of such systems into specific building projects.

One communication requirement is the provision by manufacturers of data on their systems expressly tailored to the needs of the specifiers of their products. Product line information varies in type, degree of specificity, and actual usefulness, both between manufacturers of similar types of equipment and within the range of information put out by a given manufacturer. The most explicit of that range is the specification sheet or product "spec sheet".

Manufacturers literature is the means by which producers of building materials, equipment, components, and systems communicate the characteristics and performance capabilities of their products to those in the industry who must decide which of many competing lines will actually be incorporated into a particular project. In the case of multifamily housing projects, the pertinent specifiers include architects, builder-developers, plumbing subcontractors, the latter's suppliers, and mechanical engineers (on those projects where an engineer is a part of the design and build team).

Information provided can range from general, public relations-type descriptions of the manufacturer's capability and status to specific details about construction, assembly, performance, installation, sizes and sizing methods, warrantee, delivery, and service of the actual components he produces. It is the latter kind of information which is of most concern to the specifier and which is normally incorporated into the traditional specification sheet. At the end of this section is presented a proposed version of the SAGE system spec sheet. It reflects no particular commercialization plan (e.g., outright manufacture and sales, leasing, or as an energy service).

An integral part of the utilization analysis is an extensive survey of the various markets which will be affected by or will impact the success of a commercialized SAGE system.

Two small surveys and a large market research analysis are being done to evaluate user reactions and comments. GASCO maintains questionnaires at El Toro to be filled out by visitors to the installation. The results from this questionnaire have not yet been analyzed.

Residents of The Timbers were questioned in person both during the actual installation and following several months of operation. Although not scientific in any way, the comments made are similar to evaluations made about consumer attitudes, diffusion and market penetration in other studies done previously as well as for SAGE. In the beginning, the residents were suspicious of the system and did not know how the system worked. After the system had been operating, the residents were extremely happy with it.

The large market survey is being administered by a market research firm in Southern California. The broad purpose of the survey is two-fold:

- To determine the acceptability of the SAGE concept overall and in terms of the strengths and weaknesses of marketing and policy related components of the program.
- Based on the measures of acceptability, to suggest ways of maximizing the potential for SAGE.

The surveys will be conducted in 14 cities around the U. S. plus Los Angeles. Those cities are:

Newark
Pittsburgh
Poughkeepsie
Boston
Chicago
Detroit
Madison
Wichita
Charleston
Louisville
Dallas
Washington, D. C.
Seattle/Everett
Tucson

In total, there are 15 survey targets ranging from residential builders to trade union officials with sample sizes as follows:

	Sample Size		
	Total	Los Angeles	Remainder of United States
Residential builders	120	60	60
Commercial industrial builders	120	60	60
Architects	100	50	50
Owners of multifamily buildings	120	60	60
Owners of commercial/ industrial property	120	60	60
Industrial firms:			
Heavy users of hot water	120	60	60
Lesser users of hot water	120	60	60
Commercial firms:			
Heavy users of hot water	120	60	60
Lesser users of hot water	120	60	60
Residents of multifamily rental units	300	150	150
Condominium/townhouse owners	300	150	150
Single-family residence owners	300	150	150
Financial planners	100	50	50

	Sample Size		
	Total	Los Angeles	Remainder of United States
Mechanical contractors	100	50	50
Trade union officials	100	50	50
Total	2260	1130	1130

Surveys have been designed and a pilot test conducted. The final field surveys will be conducted in September and October 1976. Final results are planned to be available by mid-January 1977.

Extensive work has been done in evaluating alternative policies and strategies that could be taken by state and federal agencies to contribute to the widespread use of SAGE water heating and other solar energy systems. The following is a summary of those policies.

1. Incentives for Consumers

- Property Tax Deduction — Property owner may deduct part or all of the solar equipment costs from his property tax.
- Income Tax Deduction — The homeowner would deduct this amount from his adjusted gross income as he does interest or medical expenses. With our graduated tax structure, however, the actual savings from a deduction increases as the tax bracket increases.
- Income Tax Credit — The homeowner may reduce his actual tax liability by a fixed amount, so that its value is independent of the income level of the taxpayer.
- Direct Subsidy — Avoiding the tax structure, with the Government paying part of the solar equipment's initial cost or part of the annual mortgage cost.
- Use and Sales Tax Elimination — Reduces investment by elimination of use and sales taxes.

- Guaranteed and Insured Loans — The Government can help overcome mortgage availability difficulties by qualifying solar-equipped homes for the Federal Housing Administration and Veteran's Administration mortgage programs. The Home Federal Savings of San Diego offers private loans for solar heating and cooling purposes.
- Availability of Mortgage Money — This would assure the financing of the incremental cost of solar equipment.
- Low Interest Federal Financing — This type of loan for all or part of the solar equipment cost could reduce the monthly mortgage payments.
- Guaranteed Insurance — This would help overcome the reluctance of private insurance companies to insure untested solar-equipped buildings.
- Accelerated Depreciation — Allows rapid amortization of the solar equipment cost, increasing the available cash flow over a shorter period.
- Investment Tax Credit — This would reduce the cost of the investment by the amount of the credit, therefore increasing the rate of return.

2. Incentives for Producers

- Tax incentives — The Investment Credit or accelerated depreciation scheme would benefit manufacturers of solar energy equipment by reducing initial production costs, and consequently lower the equipment cost for the consumer.
- Research and Development — Through direct funds to private industry or by giving them greater incentive to undertake R&D with their own funds. At one time the U.S. Treasury considered giving a tax credit for R&D expenditures.
- Architects and Builders — The assurance that architects and builders will have technical assistance can reduce delays in installing equipment and allow greater assurance of the overall quality of the

system. Compensation for delays will aid in early market penetration. Increased delivery times, complexity of systems and improper early operation should be offset by reasonable reimbursement.

3. Market Incentives

- Capital Formation — Assurance of low cost money through federal loans, loan guarantees or by special arrangements with customers could stimulate capital.
- Utility Schemes — A public utility could finance the purpose of solar heating and cooling units by their customers. With the consumer repaying the utility as part of their monthly energy bill. Another possibility would find public utility bonds becoming income tax free, with the interest cost dropping, thereby saving the energy consumer money and encouraging capital formation.
- Capital Gains Treatment — A deferral of payment of the capital gains tax on profits derived from investment in technological ventures if the profits were promptly reinvested in solar energy technology operations. This plan is analogous to a homeowner selling his home and reinvesting in a new home within 18 months.
- Guaranteed Federal Purchase or Market — Solar-equipped buildings could be built under government contract. This would cover military buildings, post offices, schools, correctional institutions, public housing, hospitals and many others. A minimum price guarantee for solar energy would guarantee that future fuel prices would not out compete solar systems.
- Regulatory Procedures — Regulatory agencies can decide what rate of return to allow a utility company. For example, a 9% rate of return on solar equipment manufactured and leased by the utility would allow a 2% after tax profit over equivalent capital invested in conventional systems.
- Direct Subsidies — Possibly in three areas: (1) R&D and information gathering and dispensing facilities, (2) construction and operation of demonstration pilot plants, and (3) capital and operating costs incurred with commercial-scale projects.

In previous work done on the building industry and the barriers to innovation,[3] three particular responses emerge which need to be overcome in order to make SAGE water heating a viable commercial water heating alternative. Those three responses are a sensitivity to the additional first costs of a solar system, the lack of available information, either performance or specification, and the risk involved in specifying a new subsystem component. Table 16 is an example of policy options which could be used to reduce some of these industry barriers to the use of solar energy.

Table 16. Policy Options Which Reduce Industry Barriers to the Use of Solar Energy

Barrier of Industry Response	Policy Option	Possible Positive Effect	Possible Disadvantage
1. First-Cost Sensitive	A. Deregulation of domestic fossil fuels	Improve solar energy cost competitiveness.	Consumer resistance and therefore political problems.
	B. Require life-cycle costing	Eliminates first-cost as only criterion for HVAC selection.	Difficult to implement; possible hidden resistances. Easy to manipulate.
	C. Financial incentives 1. Tax abatement 2. Tax credit 3. Low interest loans	Reduces direct-cost, provides direct incentive for use of solar energy systems.	May produce less efficient solar energy systems.
2. Information-Cost Sensitive	A. Clearing house or data bank/special purpose library	Provides a central place for developer to get information.	Does not help user translate information into usable form.
	B. Active dissemination (Implementation Center)	Provides necessary information and in the proper form so that it can be understood by the user.	Expensive and requires public advocate.
3. Risk-Aversion	A. Demonstration program	Provides direct evidence of the feasibility of solar energy, if done properly.	May not be done in a manner which potential users find relevant, requires additional time.
	B. Institutional Actions (Implementation Center)	Paves way for the elimination of certain critical barriers such as codes.	Difficult to accomplish since barriers in this class often lack a single focus.

SOLAR-ASSISTED GAS ENERGY DOMESTIC WATER HEATING

MULTI-FAMILY: CENTRAL HOT WATER SYSTEMS

SAGE is a system which utilizes the sun's energy to replace, on an annual basis, approximately two thirds of normal energy required to heat cold-water makeup in domestic hot water systems for multi-family buildings. It does so by placing a new energy collection and storage system between the city water line and the conventional house hot water system. This solar sub-system is made up of a series of interconnected solar collector panels mounted on the roof, a loop of collector piping, and a loop of piping between city supply and the conventional system inlet. A hot water storage tank is placed in the second loop. This loop also contains a tempering tank, which protects the user from any sudden surges of solar-provided, abnormally hot water. The first, or collector loop, also incorporates an expansion tank which prevents collector damage in the event of unexpected interruption of flow within the collector loop. The two loops by-pass each other through a tube-in-shell heat exchanger, providing an efficient transfer of energy while insuring that the potable water supply cannot be polluted by corrosion inhibitors, anti-freeze solutions, or any other toxic substances which may be required for a particular installation. A differential thermostatic controller coordinates system functions in order to maximize effective energy collection over the seasons.

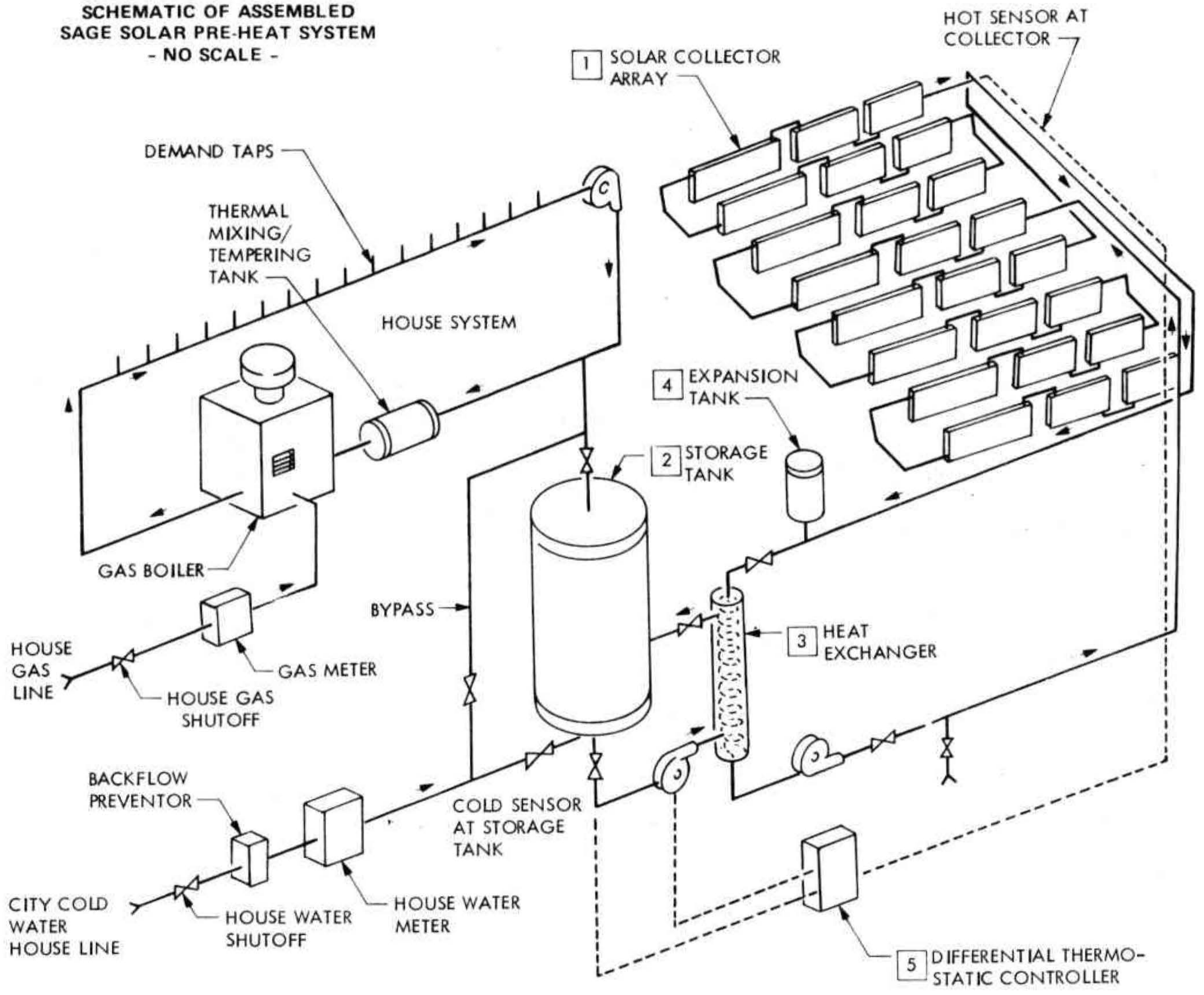
As a pre-heater, SAGE will work with most potable, gas-fired hot water heating systems, in projects of between 10 and 100 dwelling units. SAGE is shown in the diagram below as an assist to a single loop conventional hydronic system equipped with a fast firing boiler.

Many of the SAGE system elements are conventional, high-quality plumbing, electrical, or gas appliance components. Pumps and valves are all bronze and piping is copper throughout. Where applicable, each such component bears appropriate American Gas Association, ASME, or U/L ratings or certifications. Careful production and assembly quality control procedures have been established and are monitored in the manufacture of the few unique solar components, such as collectors and thermostatic controllers. The collectors meet the National Bureau of Standards Interim Performance Requirements for Solar Energy. All plumbing and tanks are insulated when mounted exterior to the building or in un-heated spaces. When designed as shown here and put into place by qualified installers, the entire SAGE solar pre-heat sub-system is AGA approved.

Since SAGE is installed with full conventional back-up, the tenant is assured of an ample supply of hot water at all times. Experience shows that SAGE is an effective and economic fuel saver.

2 JUNE 1975 (OBSOLETE)
REV. 6/6/75 (OBSOLETE)
REV. 7/2/76 (VERSION NO. 2 AS INSTALLED IN THE TIMBERS,
EL TORO, CALIFORNIA DEMONSTRATION SITE)

SCHEMATIC OF ASSEMBLED SAGE SOLAR PRE-HEAT SYSTEM - NO SCALE -

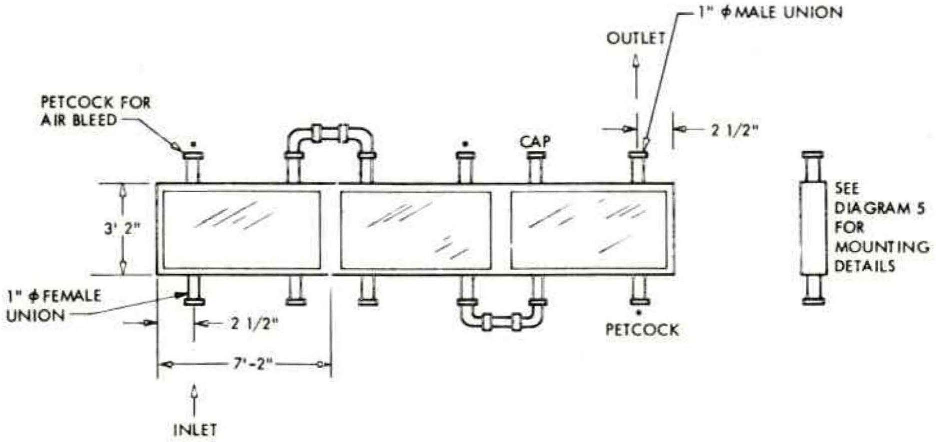


MAJOR SYSTEM COMPONENTS

No.	Title	Sizing for 40 Unit Apartment	Remarks
1	SOLAR COLLECTORS	48 Panels @ 21 ft^2 /ea. = 1008 ft^2 Array	Vertically or Horizontally Mounted in Series-Parallel.
2	STORAGE TANK	4'-6" Diameter x 11'-3" Long = 1220 gal.	Rated (Pressure and Lining) for Domestic Hot Water Service
3	HEAT EXCHANGER	5" Diameter x 6'-0" Long = 9000 Btuh/hr. °F	Min. 25 gpm flow, Each Side
4	EXPANSION TANK	2'-0" Diameter x 5'-3" Long = 100 Gal Air 150 Gal H_2O	
5	DIFFERENTIAL CONTROLLER	"Rho Sigma" Thermostat Model 102	Set @ 20°F Turn-On/ 3°F Turn-Off

[1] SOLAR COLLECTORS

Individual Collector Panels



Specifications:

Aluminum Shell, Back Panel, and Glazing Stops

(2) Layers Double Strength (D.S.) Tempered Glass in Neoprene Beading

3" Fibreglass Insulation on Back, 1" at All Edges

Weight: 6 lb./ft^2 of Collector, Including Water

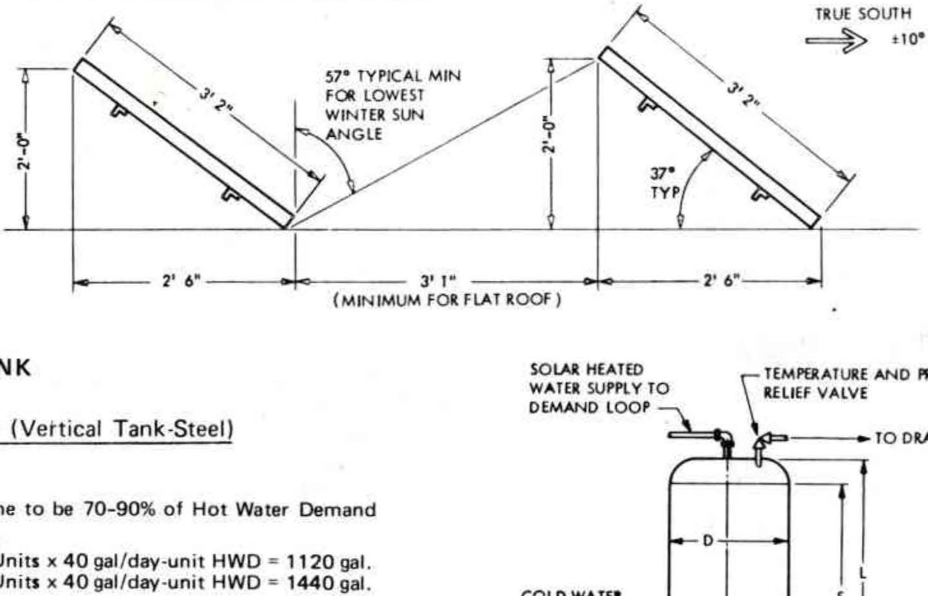
Copper Tubing on Copper Absorber Plate with Brazed Attachment and Unions

Collector Maximum Operating Pressure = 125 psi.

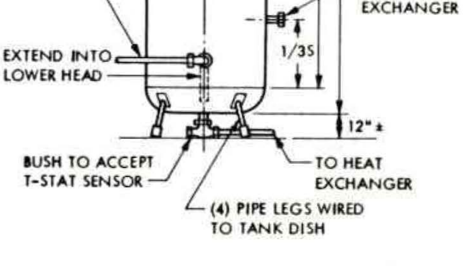
Sizing Example:

Total Required Area = 78% of Hot Water Demand (HWD), Assume HWD ≈ 40 gal/day-dwelling unit
.78 x 40 Units x 40 gal/day-unit = 1248 ft^2 60 Panels x 21 / /panel = 1260 ft^2, Therefore O.K.

Collector Angular Mounting and Spacing Requirements



[2] STORAGE TANK



Sizing Example (Vertical Tank-Steel)

S 2D

Tank Volume to be 70-90% of Hot Water Demand

Trail Sizing:
.7 x 40 Units x 40 gal/day-unit HWD = 1120 gal.
.9 x 40 Units x 40 gal/day-unit HWD = 1440 gal.

[3] HEAT EXCHANGER

Sizing Example

UA = 9 Btuh/°F x Net Collector Area, ft^2

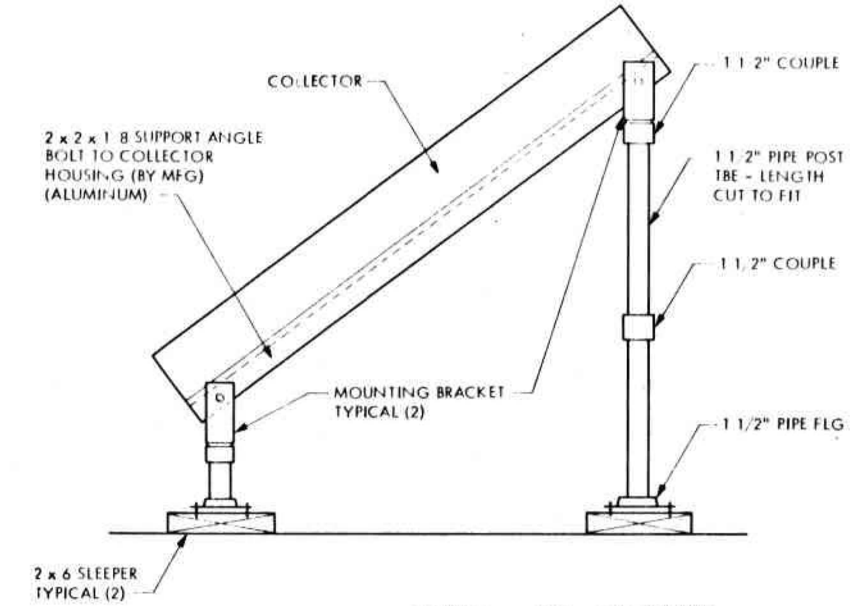
Coll. Area = 1260 ft^2

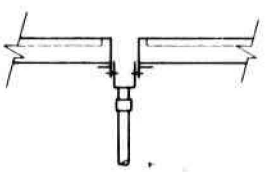
UA = 9 x 1260 ft^2 = 11,000 Btuhr/°F

Size for 11,000 Btuh = Approx. 5"x 72"L.

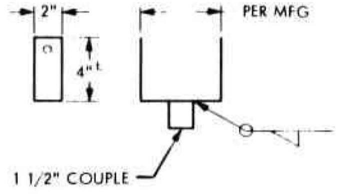
INSTALLATION AND ARCHITECTURAL DETAILS: COLLECTOR ARRAYS

Collector Mounting Details - Free-Standing on Flat Roof





(END VIEW - COLLECTOR ASSY)



(MOUNTING BRACKET)

FOR FURTHER INFORMATION:

Representatives

Richard Schoen
School of Architecture and Urban Planning
UCLA
(213)825-1345

Alan Hirshberg
Jet Propulsion Laboratory
Caltech
(213)354-6520

Distributor

James Rice
Southern California Gas Company
Research Division
(213)689-2986

Sales/Service Engineering

Ralph Bartera/Ab Davis
Jet Propulsion Laboratory
California Institute of Technology
(213)354-3305 (213)354-7004

V. SUBSYSTEM PERFORMANCE

Because of the trial nature of the pilot plant and the configuration changes that were made during the testing, comments on pilot plant subsystems will be made only as they impacted the design of the installation at The Timbers.

A. SOLAR COLLECTORS

The collector panels at The Timbers are prototypes manufactured from technology transferred from JPL experience with the pilot plant collectors.[4]

1. Physical Configuration

The 48 panels are divided between two buildings - 24 on each roof in 2 banks with 12 panels in series in each module (Fig. 12). The collectors have an aluminum shell, back panel and glazing stops and two layers of double strength tempered glass in neoprene beading (Fig. 13). The absorber plate and tubing are all copper. The plate is made up of eight 0.016 m (5/8 in.) OD tubes, 0.11 m (4.5 in.) on center, with 0.51 mm (0.02 in.) copper fins soldered to each tube (Fig. 14). Copper tube headers of 0.025 m (1 in.) OD connect the tubes running through the fins. Fiberglass 0.076 m (3 in.) thick insulates the back of the plate with 0.025 m (1 in.) on all edges.

The outer dimensions of the collectors are 2.18 x 0.95 x 0.1 m (7 ft 2 in. x 3 ft 2 in. x 4 in.) with an aperture of 2.13 x 0.91 m (7 x 3 ft). The collectors weigh 6.82 kg/m^2 (6 lb/ft^2) including water and have an operating pressure of 862 Kpa (125 psi).

The collectors are mounted on the roof (Fig. 15) with 0.04 m (1 1/2 in.) OD pipe posts tied to 0.05 x 0.15 m (2 x 6 in.) wood sleepers.

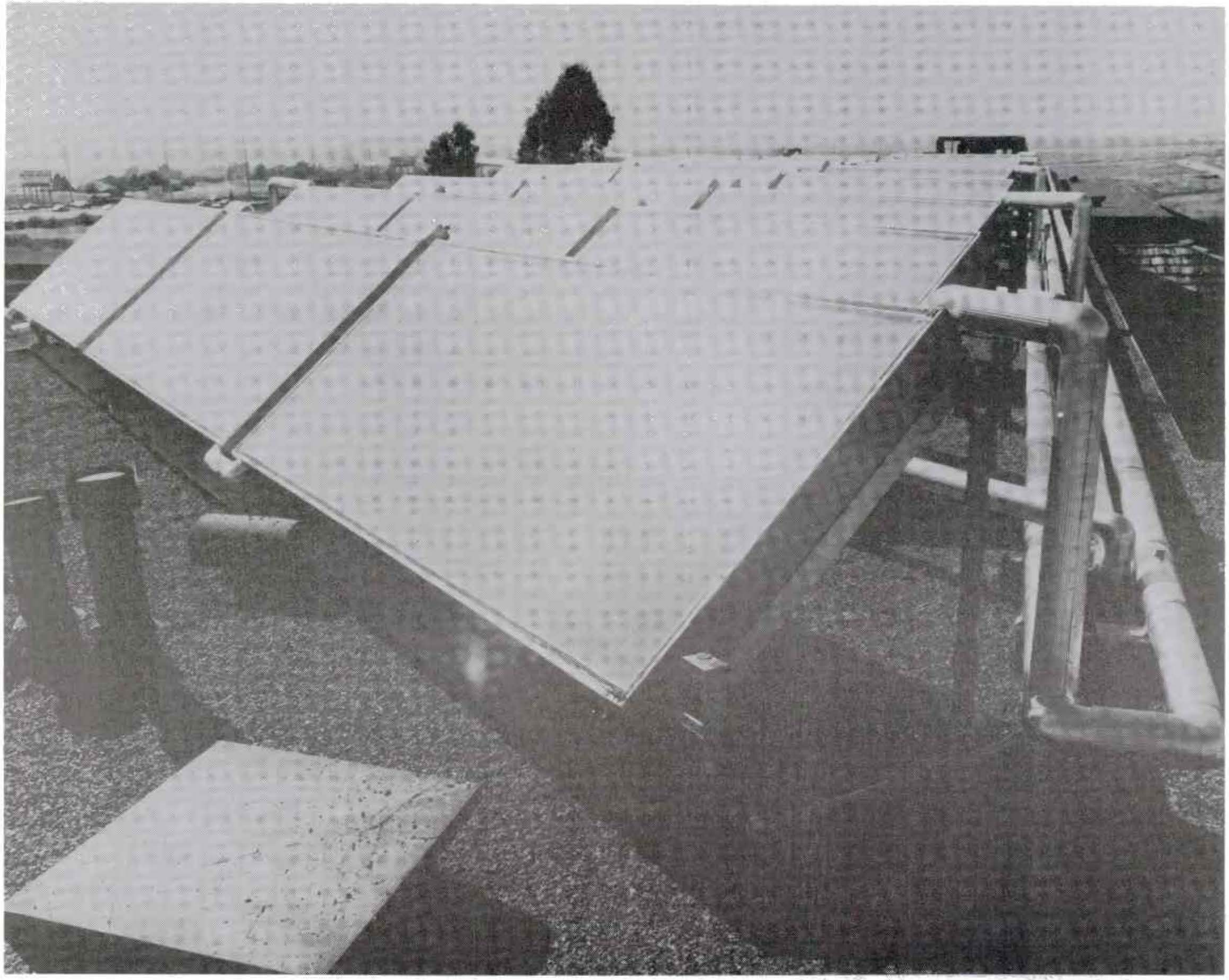
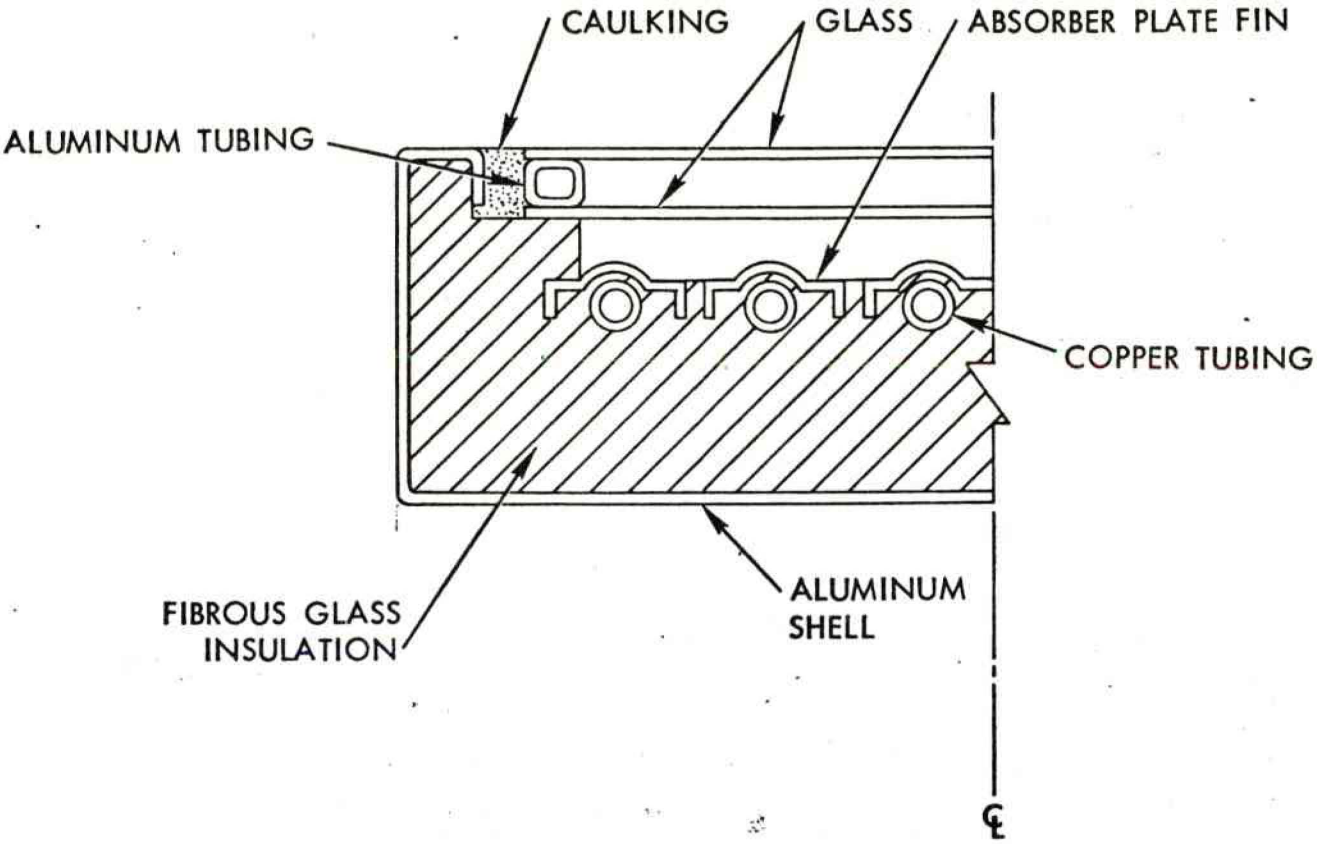


Fig. 12. Solar Collectors on Roof of The Timbers,
El Toro, California

NOT TO SCALE



- OVERALL DEPTH = 0.1 M (4 IN.)
- ABSORBER PLATE IS 0.51 MM (0.020 IN.) THICK WITH 0.016 M (5/8 IN.) O.D. TUBES
- ALUMINUM SHELL IS 0.81 MM (0.032 IN.) THICK: TOP ROLLED EDGE IS 0.025 M (1 IN.) WIDE
- ALL GLASS IS DOUBLE-STRENGTH TEMPERED: SEPARATION IS 0.013 M (1/2 IN.)
- ABSORBER PLATE IS 0.019 M (3/4 IN.) BELOW INNER GLASS

Fig. 13. Collector Panel Section — The Timbers, El Toro, California

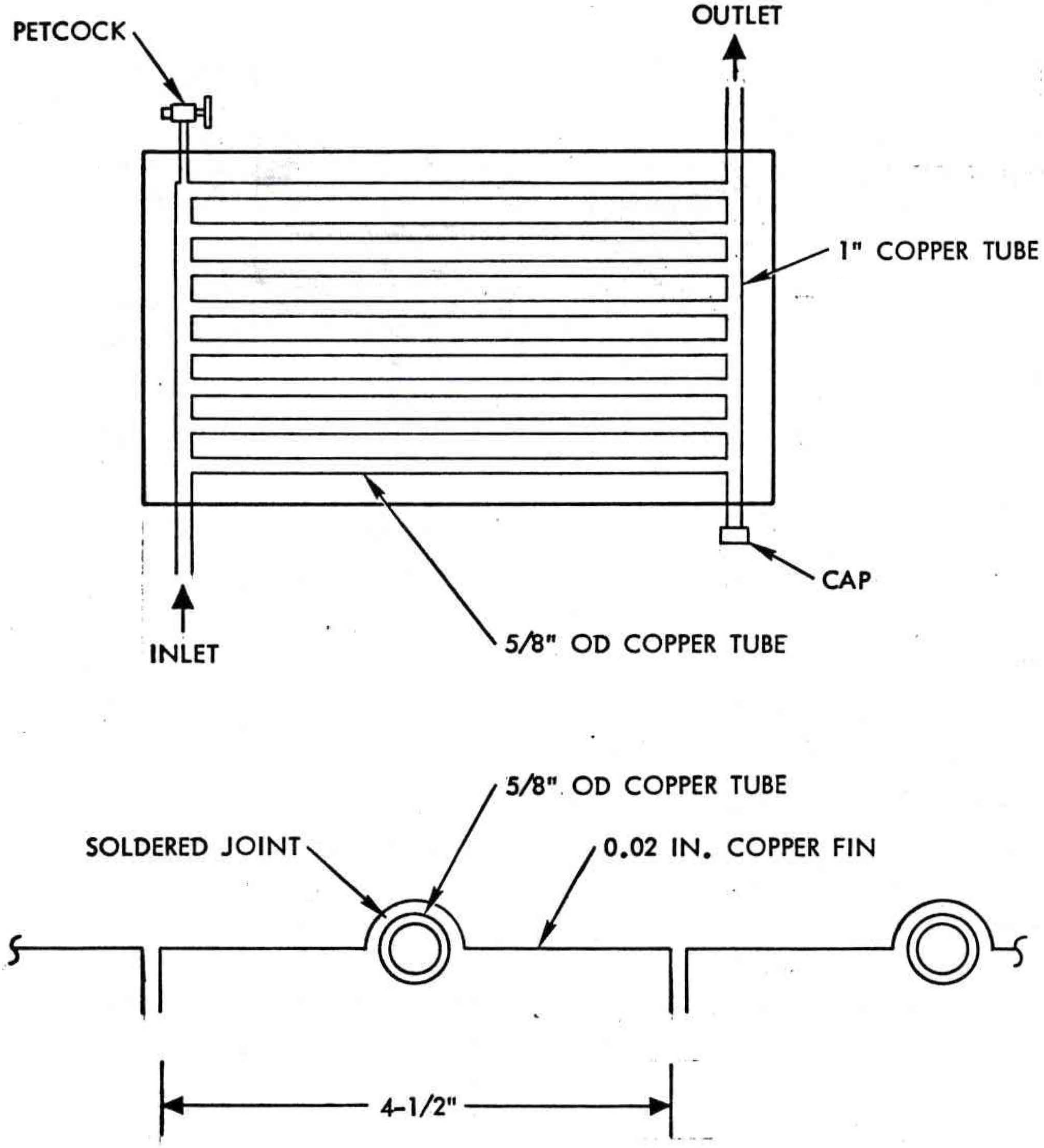
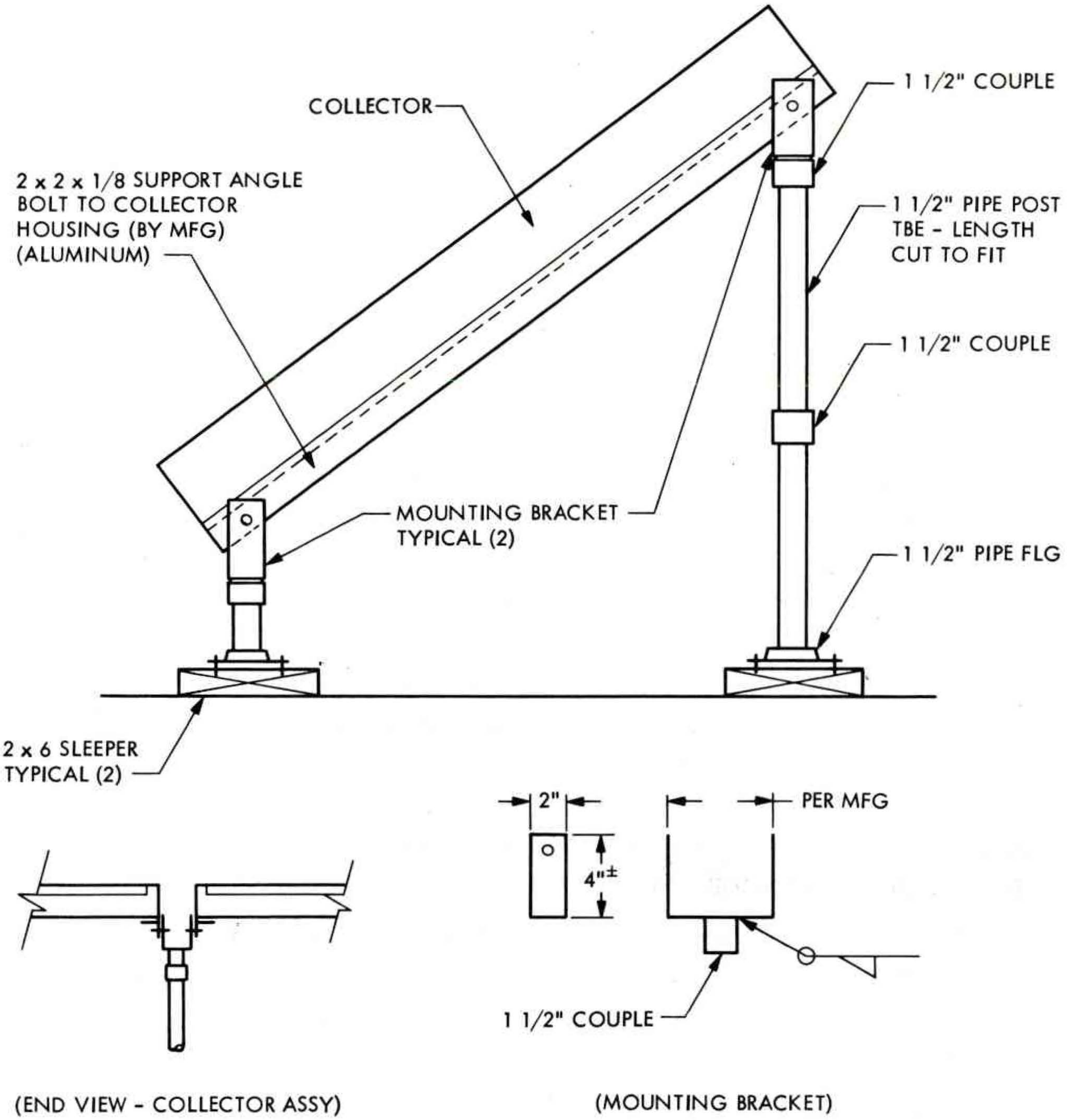


Fig. 14. Collector Absorber Plate – The Timbers, El Toro, California



(END VIEW - COLLECTOR ASSY)

(MOUNTING BRACKET)

Fig. 15. Solar Collector Mounting Detail – The Timbers, El Toro, California

2. Thermal Performance of the Collectors

In order to determine the performance parameters of a solar collector, quasi-steady state conditions must be maintained for at least one full day. Performance of The Timbers solar panels could not be calculated with any degree of accuracy because of the fluctuation in demand which caused temperature fluctuations in the collector circuit.

JPL as a part of Project SAGE has recently developed techniques which allow accurate prediction of the performance of flat-plate collectors. When the physical description of The Timbers solar collectors is used as input to this technique, it is found that the net absorptance is 0.73 and the net heat loss coefficient is 3.97 watts/m^2 - °C (0.7 Btu/hour/ft^2 -°F).

3. Lifetime Performance Characteristics

The collectors have performed extremely well with only a few minor problems.

- Four panels leaked on arrival from the manufacturer and two additional panel leaks occurred a short time after installation. All have been replaced.
- Corrosion occurred on the outer edge of some panels where soldering flux was not removed when pipes were soldered to the absorber plate fins. However, it has not caused any performance deterioration.

B. HEAT TRANSFER SUBSYSTEM

The Phase I system analysis suggested that a long narrow heat exchanger was the best configuration for maximizing heat transfer. Therefore, to simulate this type of equipment (which was not commercially available) six regular heat exchangers were set up in series in the pilot plant. The pilot plant test confirmed the benefit of this configuration and a special one was manufactured for The Timbers.

The heat exchanger is a conventional, single-pass, counterflow type, located between the storage tank and the collectors. It is 1.83 m (72 in.) long, 0.13 m (5 in.) in diameter and of single-walled construction. Regular domestic potable water is circulated through both sides. It is an American Standard Model, number HCE-05072, and has a conductance of 4.75 kw/hr-°C (9000 Btu/hr-°F). The flow on both sides of the exchanger is 1.57 liters/second (25 gpm) with a pressure drop of 0.689 kpa (0.1 psi) on the tube side and 57.9 kpa (8.4 psi) on the shell side.

C. HEAT STORAGE SUBSYSTEM

1. Physical Description

The storage tank at The Timbers (Fig. 16) has an outer shell of steel, glass lining and is covered with 2 inches of insulation. It has a 4620 liter (1220 gallon) capacity and is rated (pressure and lining) for domestic hot water service. With the reduction in actual demand from the estimate, the tank holds 120% of the daily hot water demand. As seen in the schematic diagram of the tank, Fig. 17, the cold water make-up line enters through the side of the tank and is directed toward the center of the bottom head where the outlet to the heat exchanger is located. By locating the pipe in this manner, the amount of cold water mixing in the tank is minimized. The pipe returning from the heat exchanger enters a third of the distance from the tank bottom, and water to the circulation loop is drawn from the top of the tank.

2. Thermal Performance

Because the data from The Timbers has not been analyzed for tank performance, data from the pilot plant will be discussed. Although there were some minor changes, performance is basically the same.

In the evaluation of alternative system configurations, it was found that good thermal stratification of the tank increased the performance of the system by 10%. Fig. 18 is a typical temperature history for the pilot plant storage tank. This is given for System SO which has heated water entering directly from the collectors. The performance, however, would be exactly the same except return water from the heat exchanger would be slightly cooler.

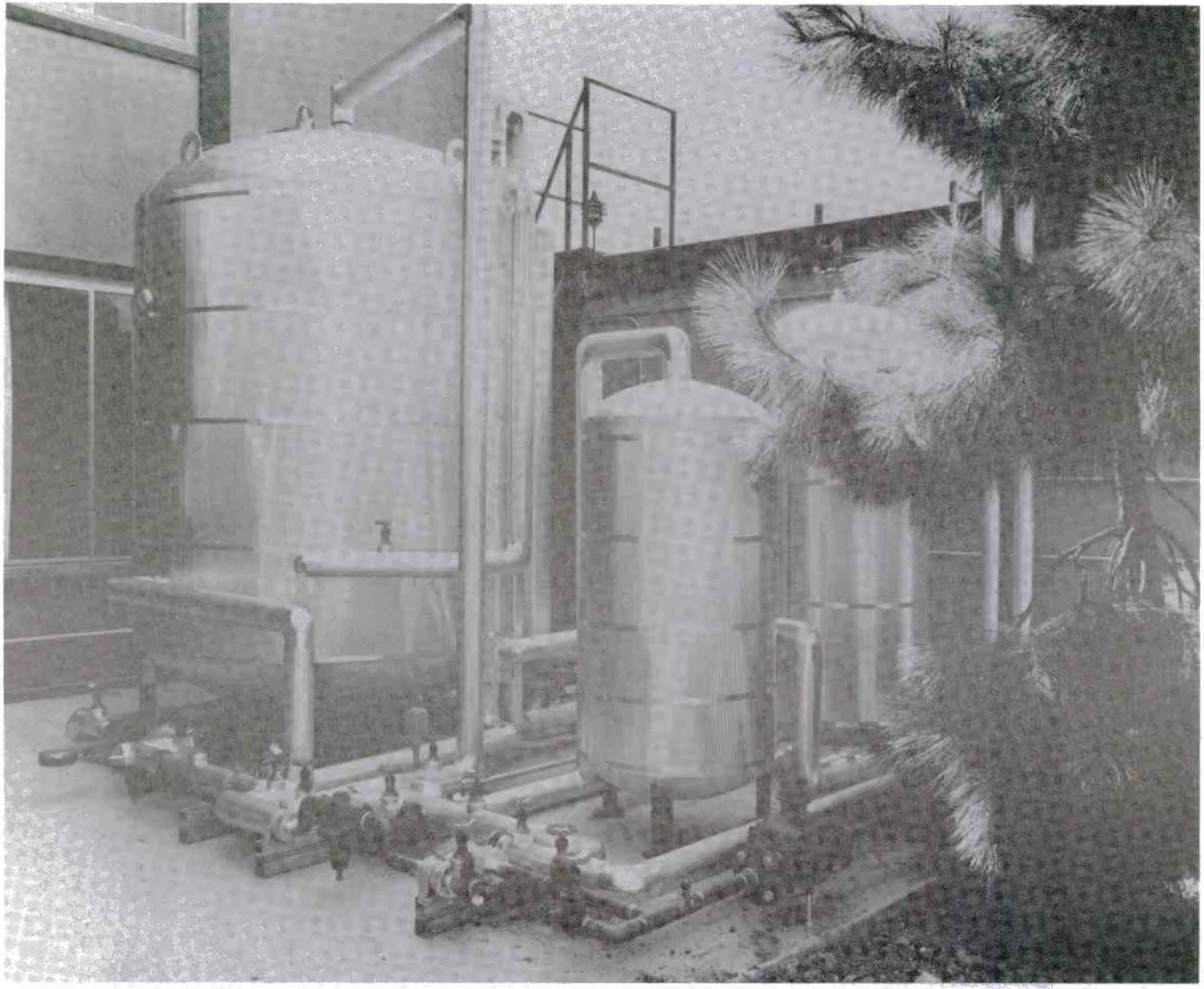


Fig. 16. Storage Tank at The Timbers, El Toro, California

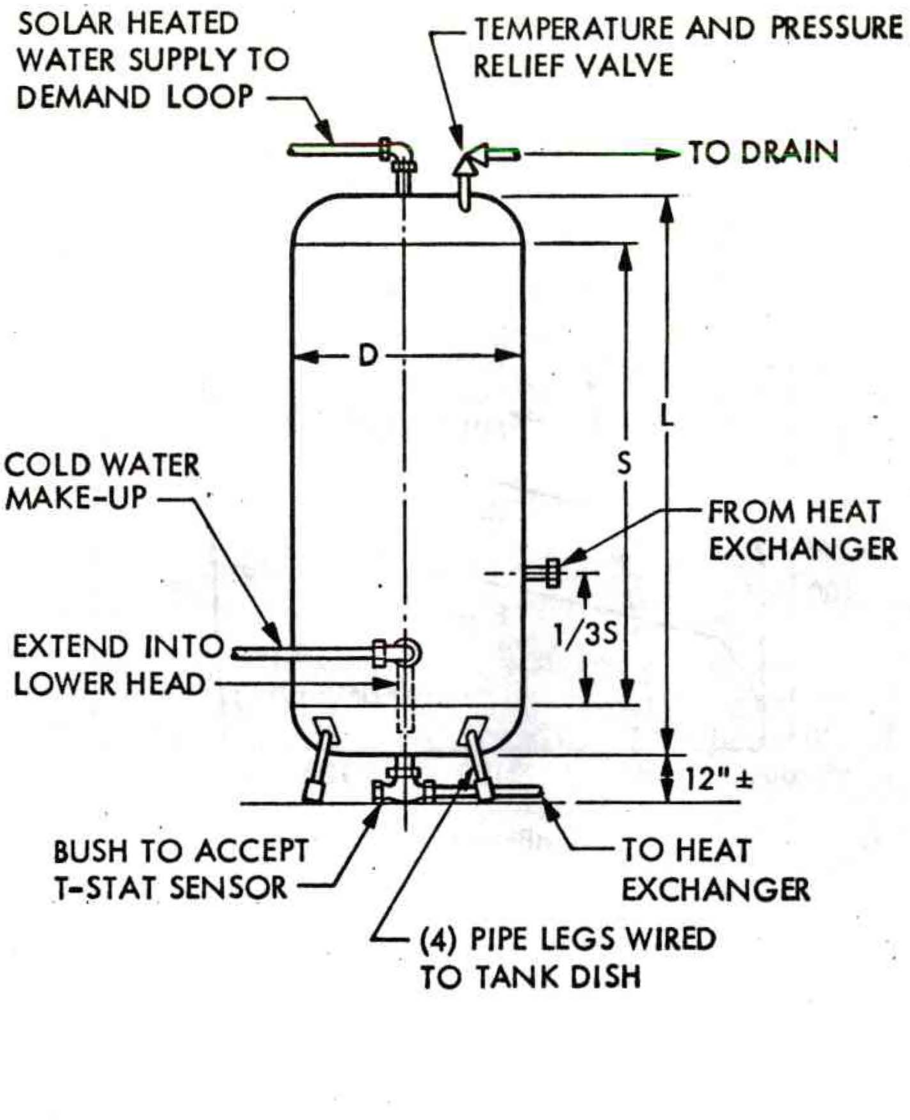


Fig. 17. Schematic of Storage Tank – The Timbers

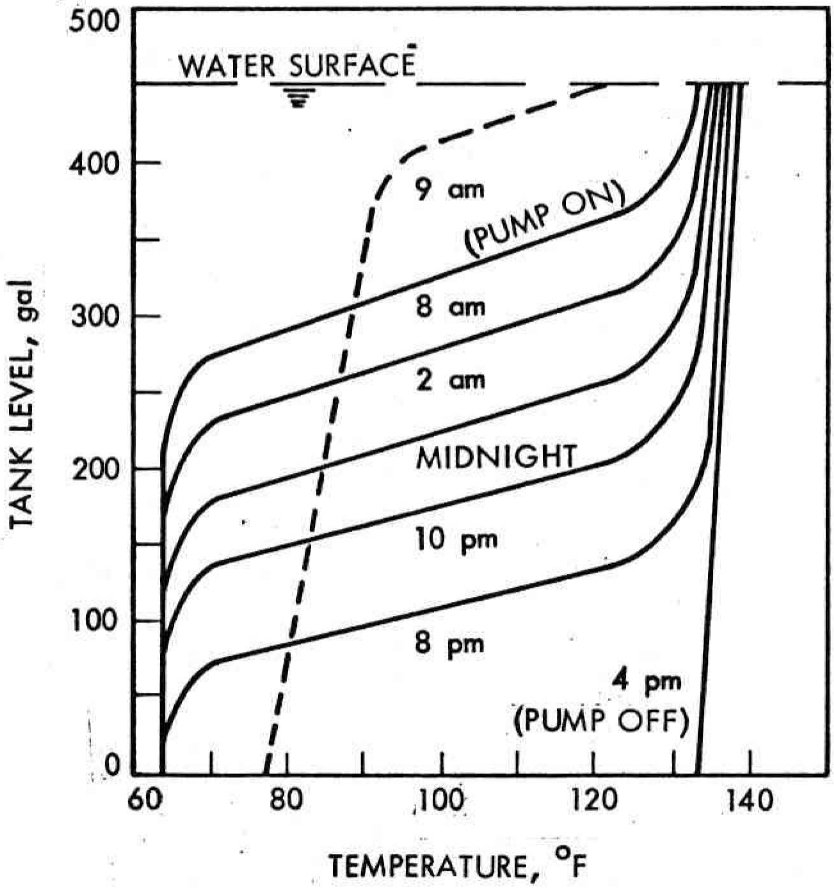


Fig. 18. Typical Storage Tank Temperatures for System SO.

It is most convenient to consider the daily cycle as beginning at the end of a solar collection period which is the curve labeled 4 PM. At this time, the energy content of the tank is highest and it is nearly isothermal. By 8 PM, the stratification is clearly apparent. A cold lower portion at the temperature of the make-up water is separated by a thermocline from a hot upper portion. As hot water was taken from the top and replaced with cold water added to the bottom, the thermocline moved upward. When the collector pump started at 8 AM, the bottom of the thermocline was at about the 930 liter (245-gal) level where the return from the collector enters the tank. That the collector flow of 0.5 liters/second (8 gal/min) did not greatly disturb the stratification is clear from the curve labeled 9 AM. The thermocline is still in evidence near the top of the tank 1 hour after the collector circulation started. Solar energy heated only the water below the thermocline which moved upward by approximately 380 liters (100 gallons) in this hour.

REFERENCES

1. Trewatha, G. T., An Introduction to Climate. (McGraw Hill: New York, 1968).
2. Bartera, Ralph E., and E.S. (Ab) Davis, Project SAGE Phase II Report, (Pasadena, California: California Institute of Technology, Jet Propulsion Laboratory Report No. 5030-15, 1976).
3. Hirshberg, Alan S., and Richard Schoen, "Barriers to the Widespread Utilization of Residential Solar Energy: The Prospects for Solar Energy in the U.S. Housing Industry", Policy Sciences, December 1974.
4. Bartera, Ralph E., and E.S. (Ab) Davis, Performance of a Flat-Plate Solar Collector, (Pasadena, California: California Institute of Technology, Jet Propulsion Laboratory Report No. 1200-179, 1974).