AD-A168 887 EVALUATION OF INSTALLED SOLAR SYSTEMS AT NAVY ARMY AND AIR FORCE BASES(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA E R DURLAK MAY 86 NCEL-TN-1750 1/1

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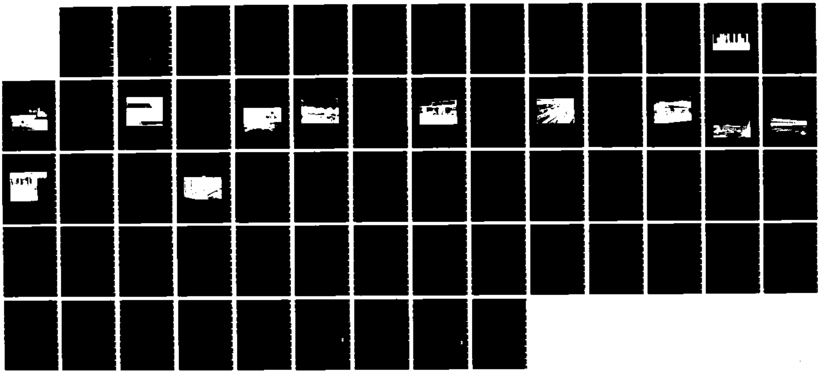

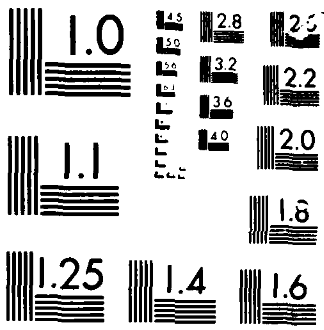
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May 1986

By Edward R. Durlak

Sponsored By Naval Facilities Engineering Command

NCEL

Technical Note

EVALUATION OF INSTALLED SOLAR SYSTEMS AT NAVY, ARMY AND AIR FORCE BASES

ABSTRACT This report presents a summary of the results of site evaluation inspections conducted at Navy, Army, and Air Force bases. The solar systems evaluated included space heating, space cooling, and domestic hot water systems. The systems range in size from small two-collector systems to large arrays installed on barracks, mess halls, office buildings, etc. These operational results are presented so that future designs will benefit from the "lessons learned" in this study.

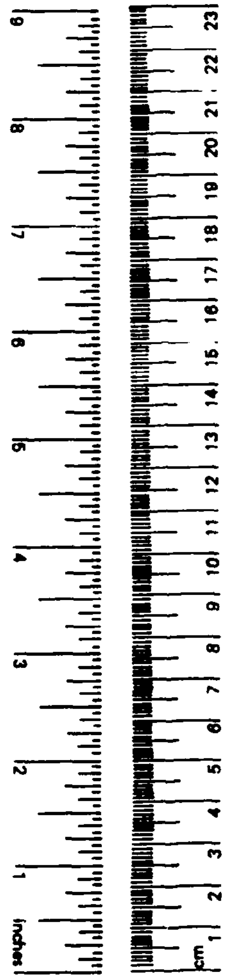
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
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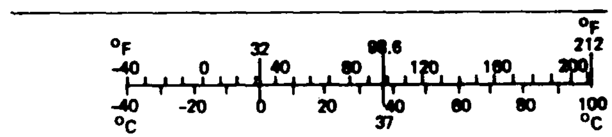
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This Report presents a summary of the results of site evaluation inspections conducted at Navy, Army, and Air Force bases. The solar systems evaluated included space heating, space cooling, and domestic hot water systems. The systems range in size from small two-collector systems to large arrays installed on barracks, mess halls, office buildings, etc. These operational results are presented so that future designs will benefit from the "lessons learned" in this study.

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Naval Civil Engineering Laboratory
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This report presents a summary of the results of site evaluation inspections conducted at Navy, Army, and Air Force bases. The solar systems evaluated included space heating, space cooling, and domestic hot water systems. The systems range in size from small two-collector systems to large arrays installed on barracks, mess halls, office buildings, etc. These operational results are presented so that future designs will benefit from the "lessons learned" in this study.

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CONTENTS

INTRODUCTION

The use of solar energy to provide domestic hot water and space heating is increasing throughout the United States in the private sector and in government applications, particularly at Navy shore facilities. The Navy has installed solar hot water systems at many bases serving the needs of family housing units, barracks, clinics, dining facilities, etc. These systems range in size from a few solar collectors to over a hundred per site. This report summarizes the results of onsite inspections conducted by the Navy, Air Force, and Army through FY85.

The purpose of this report is to give a summary of what was learned as a result of these inspections. These "lessons learned" will provide insight to improve future designs which will help insure long system life.

The report is structured so that each of the services has a separate section. The site inspection results are covered in a "Summary Sheet," and at the beginning of each section is a list of sites and Summary Sheets for each site inspected for that service. While the Summary Sheets list the problems encountered at each site, the reader may go to the Summary Sheet Review (page 48) to find a list of the most common problems.

BACKGROUND

The basic decision to install a solar heating system usually depends on the answers to the questions: how much does it cost, how well does it perform, and how long will it last? Much of the current research centers around system cost and system (or collector) performance. Little is currently being done to answer the third question of system life expectancy which revolves around the operation and maintenance of systems already installed. While not minimizing the cost or theoretical performance of solar systems, the ultimate cost-effective system will be the one that delivers reasonable performance over a long period of time. In an effort to gain operational information about existing systems, NAVFAC has tasked NCEL to perform an evaluation of solar systems already installed at Navy bases.

To accomplish the task, NCEL chose to work with an inspection team from the Los Alamos National Laboratory which, at the time, was doing similar work for the Army and Air Force. The Tri-Service arrangement will ultimately benefit each service more than if independent work were undertaken. This report includes summary sheets of each Navy solar system evaluated plus a brief review of the evaluation of 30 Army solar systems and 12 Air Force solar systems. This report is the final summary of the preliminary results given in an earlier report (Ref 1) for Navy solar systems.

DISCUSSION

The onsite evaluations were conducted by Los Alamos National Laboratory during the time period from late 1983 through early 1985. The evaluations were done with the cooperation of each service in providing candidate sites and project personnel. NCEL project personnel were present at most but not all Navy evaluations.

The purpose of the evaluations is to gain insight on design or installation deficiencies as well as to note positive aspects. The intent is to assemble information of a "lessons learned" type as a data base for developing appropriate preventive maintenance procedures and schedules. Based on the information already gathered in Reference 1, NCEL has issued guidelines on the most common faults found (Ref 2) and guidelines to troubleshoot a system (Ref 3). This information has also been incorporated to some extent in the handbook for active solar energy systems (Ref 4). Also, the data collected in this program provide the data base for a computerized "expert system" now under development by NCEL that will in effect be an automated "solar repairman" to assist in diagnosis and troubleshooting of solar systems as well as to help develop preventive maintenance programs.

The onsite inspections performed by LANL for the Navy and the other services were similar. The specific tasks that were performed were somewhat determined by site characteristics, available personnel time, and system type. For the Navy, the following were generally included at each site:

1. Determine correctness of controller logic and sensors.

2. Determine correctness of system design, orientation, and/or location.

3. Inspect overall condition of solar systems. Identify any degradation of components if found.

4. Check for material/fluid compatibility, fluid condition, and system corrosion.

5. Set up preventive maintenance program, including education of local maintenance personnel.

6. Make nonoperational sites operational if possible. Major problems requiring redesign to be made operational or to achieve optimum efficiency may be identified but not corrected within the scope of this effort.

7. Make a written summary of site status, deficiences noted, corrective actions, and preventive maintenance recommendations.

The evaluation takes 2 to 3 days per site and generally follows these steps. First a meeting is conducted with all interested parties, including engineering, design, maintenance, etc. Information is requested on system performance and their combined experience with the solar system. Drawings of the system are reviewed. Then, a percentage of the systems are inspected in a detailed manner to determine the maximum amount of information in the limited time available. This technique is relatively inexpensive and still produces useful information.

RESULTS OF SITE EVALUATIONS - NAVY

The results of each site evaluation are covered in a letter report from LANL to the individual site with copies to NCEL and other interested individuals. For purposes of this report, a one-page summary of each site evaluated is given in Summary Sheets 1 thru 11.

The sites selected were chosen with consideration given to type of solar system, material composition of collector, geographic location, budget, etc. Solar collector types included flat plates and line-focus concentrating collectors. The site locations included California, Hawaii, Puerto Rico, and New York.

The following is a reference list of Navy sites:

Location	Facility	Solar System	Summary Sheet
Marine Corps Air Station El Toro, CA	216 Family Housing Units	DHW* - Individual Units	1
Barbers Point USN PWC Pearl Harbor, HI	190 Family Housing Units	DHW - Individual Units	2
PMRF Barking Sands, Kauai, HI	Cafeteria, Quarters Support Buildings	DHW - Individual Units	3
NAVSTA Roosevelt Roads, PR	300 Family Housing Units	DHW - Individual Units	4
NAVCOMPLX, Ballston Spa, N.Y.	Family Housing, 25 four-Unit Bldgs	Space Heating and DHW	5
Marine Corps Base 29 Palms, CA	Bachelor Enlisted Quarters	DHW - Central Array - Concentrating Collectors	6
Marine Corps Base Camp Pendleton, CA	Dining Hall	Space Heating and DHW - Central Array on Roof	7
Marine Corps Base Camp Pendleton, CA	Bachelor Enlisted Quarters Bldg. no. 33605	DHW - Central Array on Roof - Flat Plate Collectors	8

Location	Facility	Solar System	Summary Sheet
Marine Corps Base Camp Pendleton, CA	Swimming Pool (500,000 gal.)	Rack Mounted, Flat Plate Unglazed Collectors	9
Barbers Point USN PWC Pearl Harbor, HI	190 Family Housing Units plus 90 New Housing Units	DHW - Individual Units	10
MCAS El Toro, CA	Bachelor Enlisted Quarters	DHW - Central Array - Flat Plate Collectors	11

*DHW = Domestic Hot Water

An attempt has been made to categorize the type of problems encountered. It should be understood that this is a difficult process since many problems could fit into several categories. Also, a single design problem may appear many times (as in family housing units) and thus the dilemma to count it once or many times. Therefore, using some judgment in this process, the problems encountered in the following summary sheets of each site can be grouped as follows:

Problem Description	Frequency
Improper Design	10 (29.4%)
Inadequate Specification	2 (5.9%)
Equipment Malfunction	9 (26.5%)
Improper Operation	7 (20.6%)
Installation Error	6 (17.6%)

The summary sheets for each site follow.

SUMMARY SHEET 1
SITE EVALUATION FOR
MCAS EL TORO, CALIF.

SYSTEM DESCRIPTION

There are 54 four-plex family housing units for a total of 216 units that have their hot water supplemented by solar systems. Each four-plex unit (Figure 1) has two solar systems. Each solar system has two solar collectors (42.8 ft^2) which feed a 100-gallon storage tank. The solar collectors are flat-plate, single-glazed, polycarbonate covers. They are all aluminum collectors and use a closed-loop, glycol solution for the system fluid. Heat exchangers are mounted on top of each storage tank. About half the collectors are tilted at 18 degrees (roof pitch) and the remaining are frame mounted at a 35-degree tilt.

HIGHLIGHTS OF EVALUATION

1. Visual inspection showed no visible corrosion or leaks.

2. Systems appeared adequately designed and installed, however, the final design and installation was different from that on the original drawings.

3. About 40% of the systems had poor performance due to inadequate charge of glycol solution in the solar loop. Systems need closer monitoring or a routine PM to correct this problem.

4. The controller and tank are located in a shed outside the unit. The controller was "locked" in a shed requiring the disassembly of many screws to open the door which was time consuming and not conducive to quick maintenance checks. Once inside the shed a convenient gage showed the state of charge of the glycol solar loop and a fill valve was readily accessible. It appeared as if special equipment from the manfacturer would be required to recharge the system.

Figure 1. Four-plex units, El Toro, Calif.

SUMMARY SHEET 2
SITE EVALUATION FOR
NAVAL STATION PEARL HARBOR, HAWAII

SYSTEM DESCRIPTION

About 190 of the family housing units at Barber's Point have a retrofit solar DHW system (Figure 2) consisting of two to four flat plate collectors which feed 66-, 82-, or 100-gallon storage tanks. A standard differential temperature controller and 1/35 hp circulating pump are used. A unique and well designed timer switch (the first the inspection team has seen) was integrated into the control logic to allow the backup heater to come on at preselected times depending on the work schedules of the occupants. The use of a timer allows the solar system to carry more of the DHW load by limiting the amount of backup energy used. This results in a more efficient system. This is a good way to limit auxiliary energy without having the occupant involved (or charge him for excess energy used).

HIGHLIGHTS OF EVALUATION

1. The solar collectors appeared to be in good condition.

2. About a dozen systems were inspected and 75% found to be working in a normal manner. In spite of noting some problems that are disclosed below, the team felt that these were well designed and constructed systems. The backup timers are an easy way to control the exact auxiliary energy used. The housing office had all the design "specs" and drawings and a good O&M manual (although they did not perform routine PM).

3. Twenty-five percent of the system problems were associated primarily with the control system (pump, controller, sensor).

4. There was evidence of occupant tampering with the backup timer, but the solar system was not affected.

5. The collector outlet sensor was found to be located too far from the collector absorber plate. This resulted in the absorber plate being at a higher temperature than what the sensor was measuring and hence what the controller was receiving as an input signal. The result did not affect system performance to any great degree, but the "hotter" collector plate tended to pump water through the pressure relief valve usually during the hot part of the afternoon (12 to 2 p.m.). This was noted by many of the residents. For safety and aesthetic reasons, it is not desirable to allow hot water on the roof frequently. It was recommended that this problem be corrected by relocating the sensor. This is an easy job, taking about 10 minutes per system. It could be done as part of routine O&M. The evaluation team demonstrated how to relocate the sensor to the appropriate personnel.

6. A routine O&M procedure was demonstrated to the maintenance personnel which, if followed, should increase the online status to about 90 to 95% for these systems.

7. Metered data of solar and nonsolar houses for 12 units showed an energy savings of about 70% average with a range of 31 to 83%. The variable savings is attributable to different occupant usage patterns.

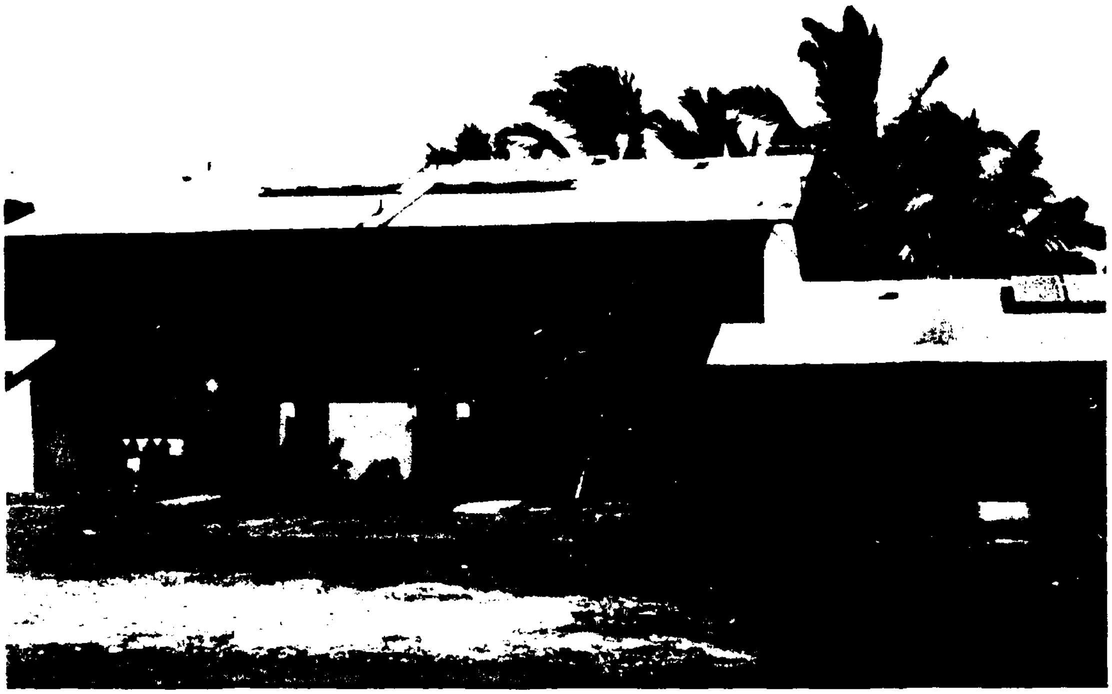

Figure 2. DHW Solar systems, Barber's Point, Hawaii.

SUMMARY SHEET 3
SITE EVALUATION FOR
PMRF BARKING SANDS, KAUAI, HAWAII

SYSTEM DESCRIPTION

This Naval Station was somewhat different in that, instead of a large number of one type of solar system, it had five separate systems installed on five separate buildings. While there were some system differences there were also some similarities.

The five systems presently installed at PMRF all use Raypack Model SG18-P collectors which are about 18 ft^2 each. Each system uses a differential temperature controller and mixing valve. All five systems are used for hot water.

- Building 201, Navy Exchange Cafeteria, eight panels, 300 gal/day
- Building 300, Aircraft Operations, four panels, 150 gal/day
- Building 412, Underwater Weapons Support, three panels, 100 gal/day
- Building 801, Transient Quarters, four panels, 150 gal/day
- Building 1262, Enlisted Dining Facility, Bachelor Enlisted Quarters (Figure 3), eight panels, 1,000 gal/day

HIGHLIGHTS OF EVALUATION

1. Three systems were found to be operating normally and of the other two one had a bad pump and one a bad controller.

2. All the other aspects of these systems seemed to show normal degradation consistent with the age of the system, which ranged from 3 to 7 or 8 years. Some corrosion was noted on the outer box of the older collectors, but did not seem to be of any concern at this point.

3. The system designs and sensor placements all appeared adequate.

4. There was some preventative maintenance performed, but the maintenance contractor was unsure what to check. The team gave him some procedures to follow.

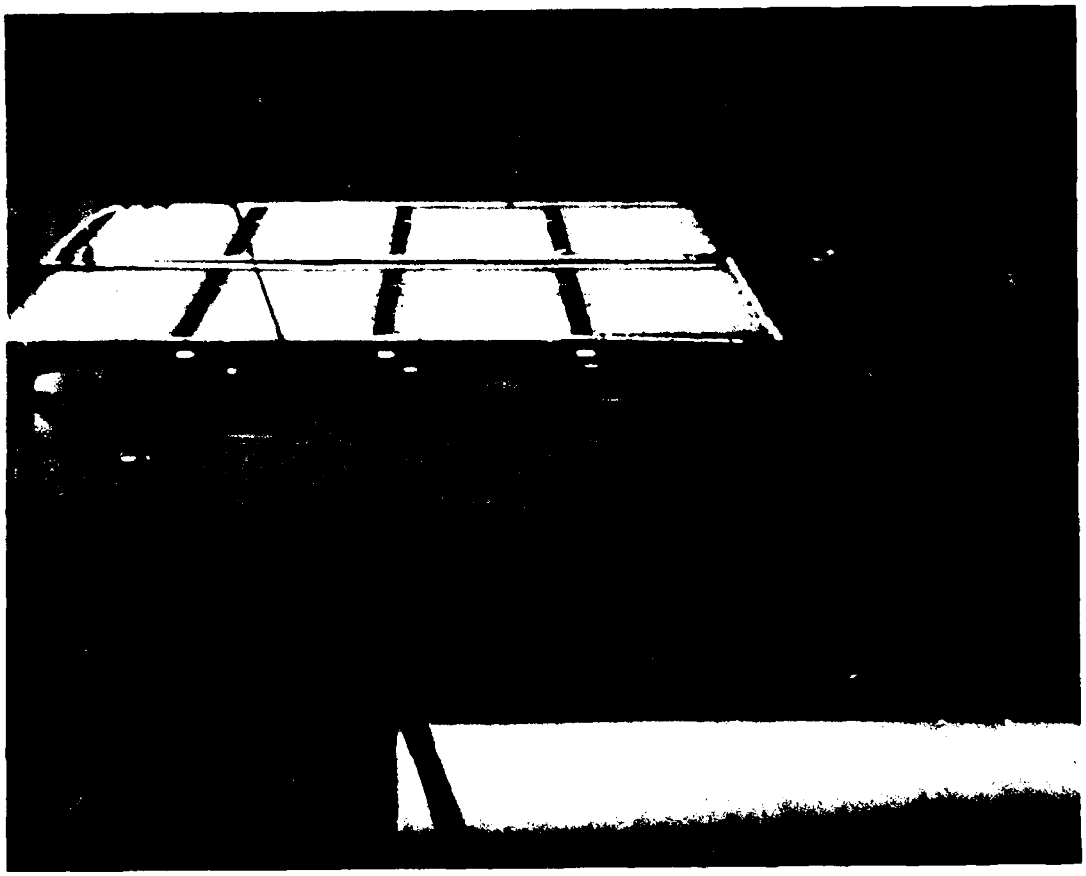

Figure 3. Dining facility, Barking Sands, Hawaii.

SUMMARY SHEET 4
SITE EVALUATION FOR
NAVAL STATION ROOSEVELT ROADS, P.R.

SYSTEM DESCRIPTION

This Naval Station has about 300 domestic hot water (DHW) systems. About two-thirds of the systems are of the thermosiphon type (no pump or controller) and one-third of the typical active type with full controls. The two types of units are as follows:

1. Thermosiphon DHW units (Figure 4) consisting of approximately 70 ft^2 of collector and 40 gallons of storage, all located on the roof. Each unit serves as preheating for 52-gallon electric DHW tanks for two apartments.

2. Active DHW units (Figure 5) utilizing approximately 40 to 70 ft^2 of collector and 40 gallons of storage located in the storage room with the existing electric DHW tank. A differential controller is used to turn on the solar-loop pump when the collector temperature is 16°F above the storage temperature and turn off the pump when the collector/storage temperature differential drops to 3°F.

Both types of systems utilize collectors manufactured by Solar Device, Inc., of San Juan, P.R. Installation was done by Premier Electric International Corporation.

HIGHLIGHTS OF EVALUATION

Thermosiphon Units

1. The majority of the systems are working well and the collectors are free of corrosion or other problems.

2. The storage tanks are insulated with sprayed urethane foam. The upper surface of the foam on most tanks has deteriorated to a point where, in some cases, cracks have developed, allowing moisture to seep in and cause the mild steel of the tank to rust. Corrective action will be required to waterproof the insulation.

3. The systems are undersized in terms of the ratio of storage volume to collector area. A ratio of 2 gallons of storage per ft^2 of collector is proper; these units have less than 1 gallon of storage per ft^2 of collector. At this point, no changes are recommended unless storage tanks have to be changed because of corrosion failure. If so, the tanks should be at least 125 gallons.

Active DHW Units

1. About a dozen active units were inspected at random. About half the units were not working for a variety of reasons including controller/pumps unplugged (occupant tampering), pump failure, and sensor failure.

2. The solar collectors are in good condition.

3. A variable speed pump/controller combination is used which has been shown to be less reliable than a nonproportional combination. No action is recommended unless parts are being replaced.

4. No regular maintenance was performed on systems.

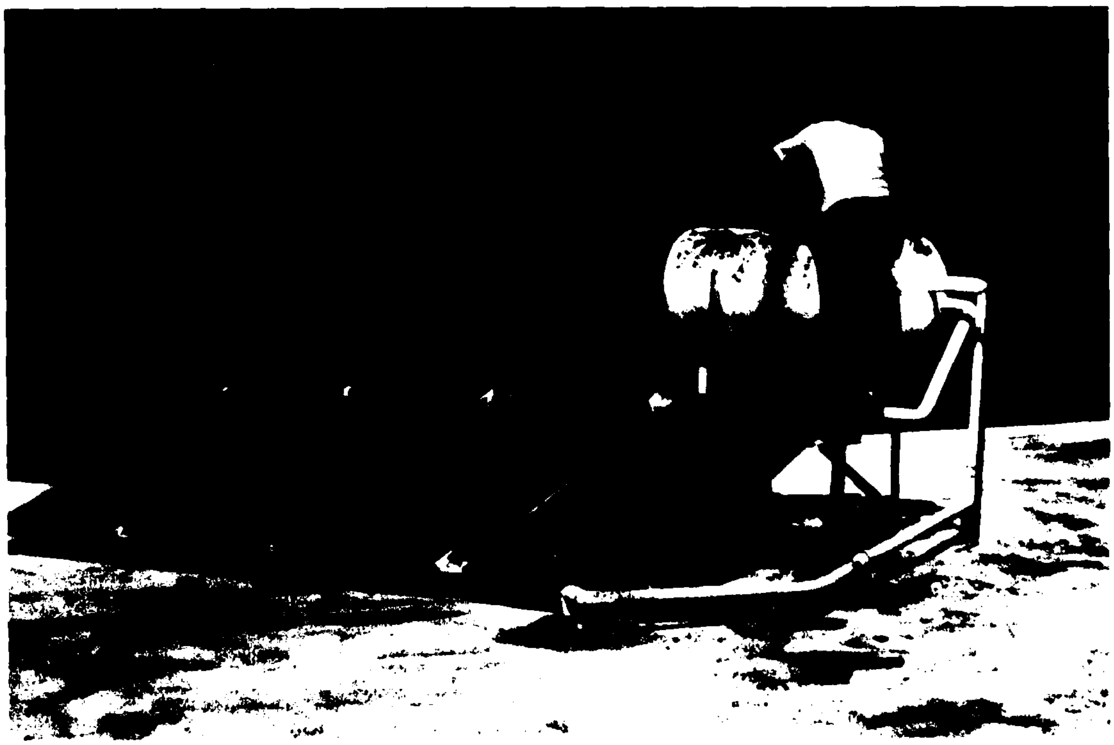

Figure 4. Thermosiphon DHW units, NAVSTA Puerto Rico.

Figure 5. Active DHW units, NAVSTA Puerto Rico.

SUMMARY SHEET 5
SITE EVALUATION FOR
NAVAL COMPLEX, BALLSTON SPA, N.Y.

SYSTEM DESCRIPTION

About 100 family housing units have a solar system that provides space heating and domestic hot water. The solar unit acts as a preheater for both functions. There are 25 buildings, each containing four living units. Each four-plex has 12 Daystar solar collectors (Figure 6) that feed one mechanical room. Each mechanical room has two large (400 gallon) concrete lined tanks that store the solar heated water. The collector loop uses glycol/water mixture with a semiautomatic makeup system in case of leaks. This site is somewhat unique in that it is located far away from other Navy installations, hence it does not have its own Public Works Center, and maintenance is hired out to a private contractor.

HIGHLIGHTS OF EVALUATION

1. The solar collectors and tanks appeared to be in good condition.

2. There was a lack of accurate system drawings, hence no adequate preventive maintenance was performed.

3. There were a number of items that related to the initial system installation:

- Insulation was missing from a number of pipes and joints.
- There were some poorly soldered joints resulting in small leaks of the glycol solution.
- No dielectric unions were used resulting in dissimilar metal contacts which could cause problems in the future.

4. A design weak point is the lack of a circulating pump between the preheat storage tanks and main storage tanks. Standby losses are high and heat is transferred only when a demand is placed on the system. Performance could be improved if a pump were installed.

5. The majority of systems did seem to be operating normally and the rest of the design appeared adequate.

6. Each house had monitored the natural gas consumption; however, there were no baseline houses without solar that were also monitored. An estimate was made on how much gas would be used on similar houses adjusted for the difference in heating degree days of the climate. From this estimate it appears that the Ballston Spa houses use about 35 to 40% of comparable gas usage of houses without solar.

Figure 6. Four-plex units, Ballston Spa, N.Y.

SUMMARY SHEET 6
SITE EVALUATION FOR
MARINE CORPS BASE, 29 PALMS, CALIF.

SYSTEM DESCRIPTION

The Bachelor Enlisted Quarters (BEQ) solar systems are designed to provide heat for domestic hot water (DHW) for approximately 318 marines in each of two buildings (Figure 7). Solar energy is collected by 144 linefocusing collectors arranged in banks of 24 units each. Each bank has a separate drive motor and tracking unit. Collected energy is transferred to a 5,000-gallon storage tank by means of a shell-and-tube heat exchanger. DHW is heated by transferring heat from the 5,000-gallon tank to two smaller 1,100-gallon tanks. The collector loop uses glycol as the heat transfer medium.

HIGHLIGHTS OF EVALUATION

1. The line focus (or parabolic dish) concentrating collectors are in good condition.

2. There is some piping insulation which should be resealed to prevent moisture damage, especially around sensor locations.

3. The ethylene glycol solution in the collector loop should be raised from 23% to a minimum of 30% (50% would be better).

4. The storage volume (7,200 gallons) is larger than the optimum (about 5,000 gallons) for this system resulting in slightly lower storage temperatures. No corrective action recommended.

5. An analysis of the flow distribution in the system showed that the collector loop flowrate of 280 gpm and the storage loop flowrate of 81 gpm did not make an efficient heat transfer through the heat exchanger. Assuming correction factors for a 30% gylcol solution versus water on the other side of heat exchange these flows should be adjusted to about 150 gpm and 137 gpm, respectively.

6. A slight adjustment of the controller "turn on" and "turn off" temperature differentials was recommended from 20°F and 5°F to 8°F and 3°F, respectively.

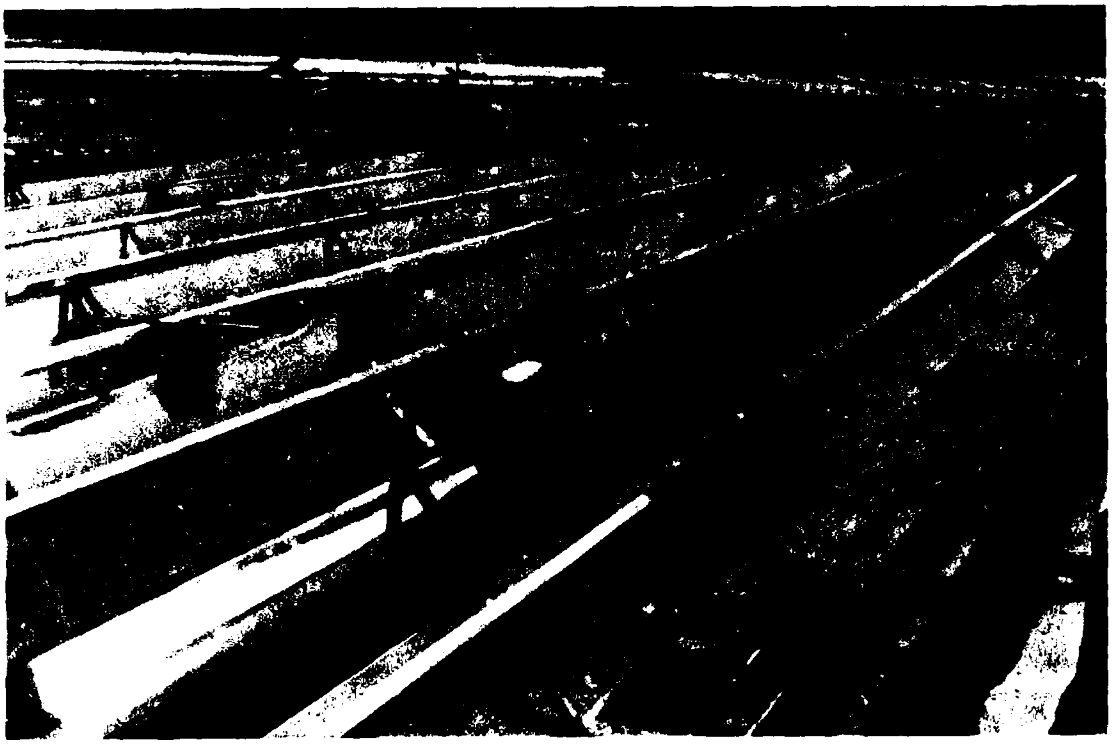

Figure 7. BEQ, Marine Corp Base, 29 Palms, Calif.

SUMMARY SHEET 7
SITE EVALUATION FOR
DINING FACILITY - MARINE CORPS BASE
CAMP PENDLETON, CALIF.

SYSTEM DESCRIPTION

The solar system on this dining facility for enlisted men provides DHW and space heating in a 14,000 ft^2 building that serves about 3,000 meals a day. The solar systems consist of 168 collectors (about 2,500 ft^2) and are built into the south facing gable roof so that they are integral to the roof structure itself (Figure 8).

HIGHLIGHTS OF EVALUATION

1. The glycol solution in the solar loop was low. There appeared to be air in the lines.

2. The storage tanks were slightly oversized at 2.9 gallons (storage) per ft^2 (collector area) vice about 1.8 to 2.0 gal/ft^2 optimum. No change is recommended, however.

3. The solar controls were interfaced with the EMCS controls. This is probably not the best approach since it leads to complexity of system control.

4. The solar collectors were fine and had normal flow. However, they were dirty due to the greasy air from the exhaust fans. They will have to be washed. It has also been a dry year, contributing to this problem.

5. It was advised to switch from a glycol loop to a recirculation loop for freeze protection to reduce the expense and volume of glycol needed.

Figure 8. Dining Facility, Camp Pendleton, Calif.

SUMMARY SHEET 8
SITE EVALUATION FOR BEQ
MARINE CORPS BASE, CAMP PENDLETON, CALIF.

SYSTEM DESCRIPTION

This is a typical two-story Marine BEQ housing about 300 persons. The solar system (Figure 9) provides DHW and consists of 120 Daystar flat plate solar collectors each about 3 feet by 6 feet to give about 2,800 ft^2 solar area.

HIGHLIGHTS OF EVALUATION

1. The piping runs were overly complicated which could contribute to poor flow distribution through the system.

2. One pump was not running due to control problems and one pump needed repair work.

3. The glycol in the system was low.

4. The solar collectors where fine and no major corrosion was noted.

5. The solar collectors were plumbed together with silicone hose and screw type hose clamps. They have had some leaks. NCEL has already recommended that constant tension hose clamps be used in place of screw type or that this method not be used at all.

6. During the first year of operation, several collector cover glazes cracked due to suspected thermal stresses. This problem is not recurring.

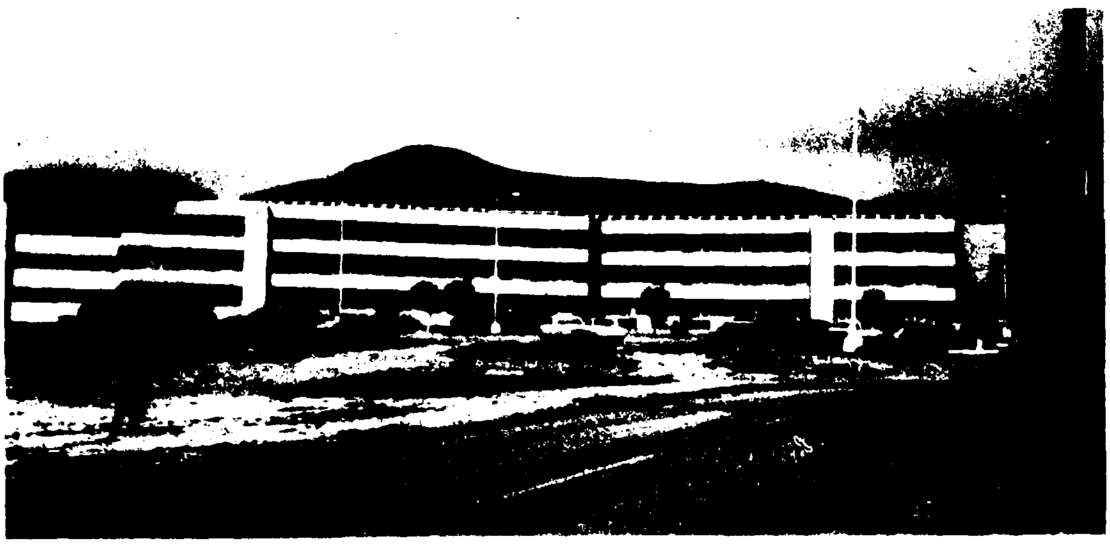

Figure 9. BEQ, Camp Pendleton, Calif.

SUMMARY SHEET 9
SWIMMING POOL, CAMP PENDLETON, CALIF.

SYSTEM DESCRIPTION

The swimming pool in the "14" area of Camp Pendleton is a 500,000-gallon pool used for recreation and combat training. The solar system consists of 152, 4 feet by 8 feet unglazed solar collectors mounted on a ground rack alongside the pool (Figure 10). The unglazed collectors use a copper tube on an aluminum absorber plate for heat collection. Due to the problems explained next, these collectors are scheduled to be replaced. All further comments address only the old system.

HIGHLIGHTS OF EVALUATION

1. The system was not operational due to a combination of control problems, air in the system, and numerous system leaks.

2. The system experienced many leaks of the collector at the joints in the header of the collector. The leaks were due to the fact that the headers will move by thermal expansion but they were prevented from moving because the absorber plate fins were bolted to the plywood rack (see Figure 11). The repeated movement and stress caused leaks and eventually corrosion of the collectors.

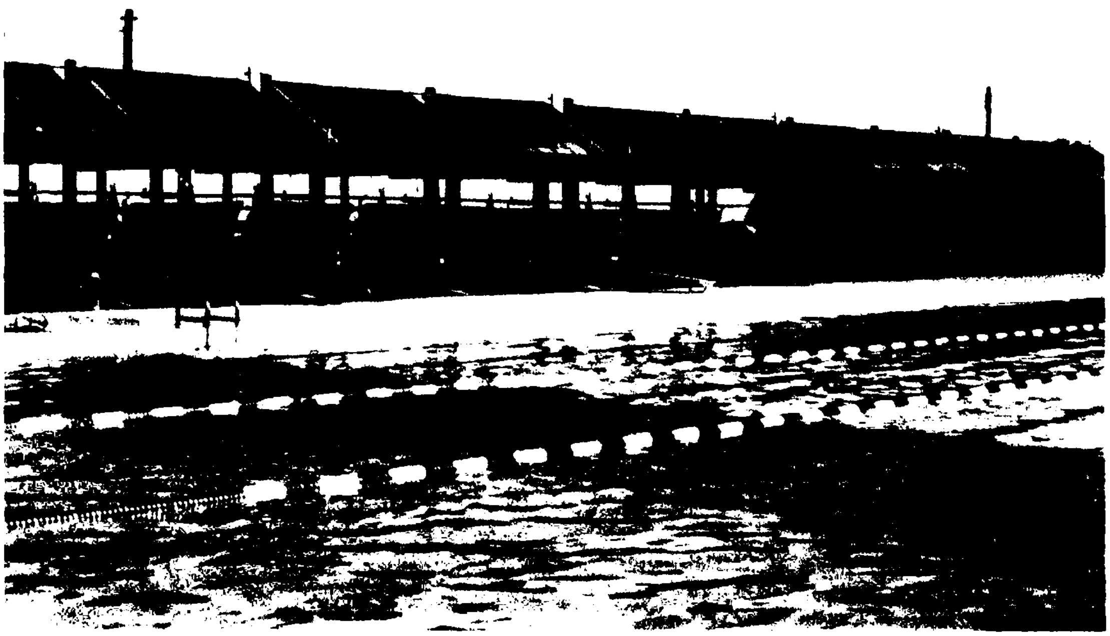

Figure 10. Swimming pool, Camp Pendleton, Calif.

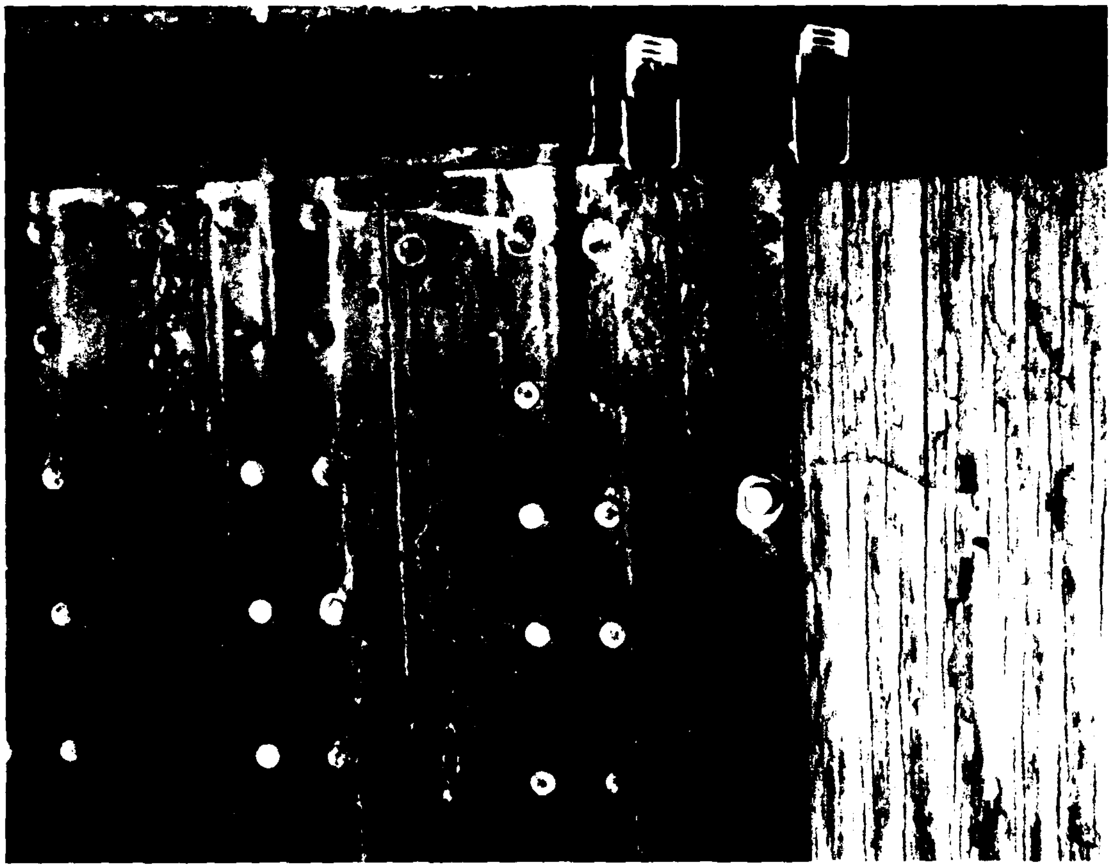

Figure 11. Solar collector, Camp Pendleton, Calif.

SUMMARY SHEET 10
BARBERS POINT, PEARL HARBOR, HAWAII

SYSTEM DESCRIPTION

These systems are the same as those described in Summary Sheet No. 2. It was decided it would be useful to reinspect a site about 1-1/2 years after the first inspection to see if the "lessons learned" had any effect on system operation. In addition, a newer system of about 90 DHW units was also checked. This system was installed in mid 1984.

HIGHLIGHTS OF EVALUATION

1. The first site inspection (June 1984) showed that about 25% of the units had some problems.

2. Results of second inspection (Jan 1985) showed that there were 53 units checked. There were two nonsolar problems, five control system problems, and about five systems with controller switch in the wrong position. If the wrong switch problems are not counted (the system still functioned), then there were seven inoperative systems out of the 53 checked. The online efficiency would be about 46/53 = 86.7%.

3. Of the 90 new solar DHW systems, 15 were inspected and there was one bad sensor and one controller switch in the wrong position.

4. Of the seven problems in the old system the majority had been reported to maintenance and were awaiting parts.

SUMMARY SHEET 11
BEQ - EL TORO MARINE CORPS AIR STATION, CALIF.

SYSTEM DESCRIPTION

There are two BEQs at El Toro MCAS that have solar systems. They both use Gulf Thermal Corporation model KYSM-40 flat plate solar collectors that are about 3.7 feet by 9.7 feet (36.6 ft^2). One BEQ has 126 collectors (4,600 ft^2) and the other 105 collectors (3,840 feet). Figure 12 shows the BEQ and solar system.

HIGHLIGHTS OF EVALUATION

1. There were problems found with the control system due to non-functioning equipment, some unconnected controls, and poor sensor placement. The sensor was located in the collector box rather than in the fluid outlet of collector.

2. Sensors placed outside near the buried storage tank were not protected from the weather and need to be replaced.

3. New controls and sensors were recommended.

4. Overall installation was professional and collectors are in good shape.

5. Flow balance needs to be done on the system. The balance valves are already installed. Flowrates were recommended.

6. The storage volume is slightly undersized. A procedure was recommended that would not require any more storage tanks.

7. There was no O&M manual for this complicated system.

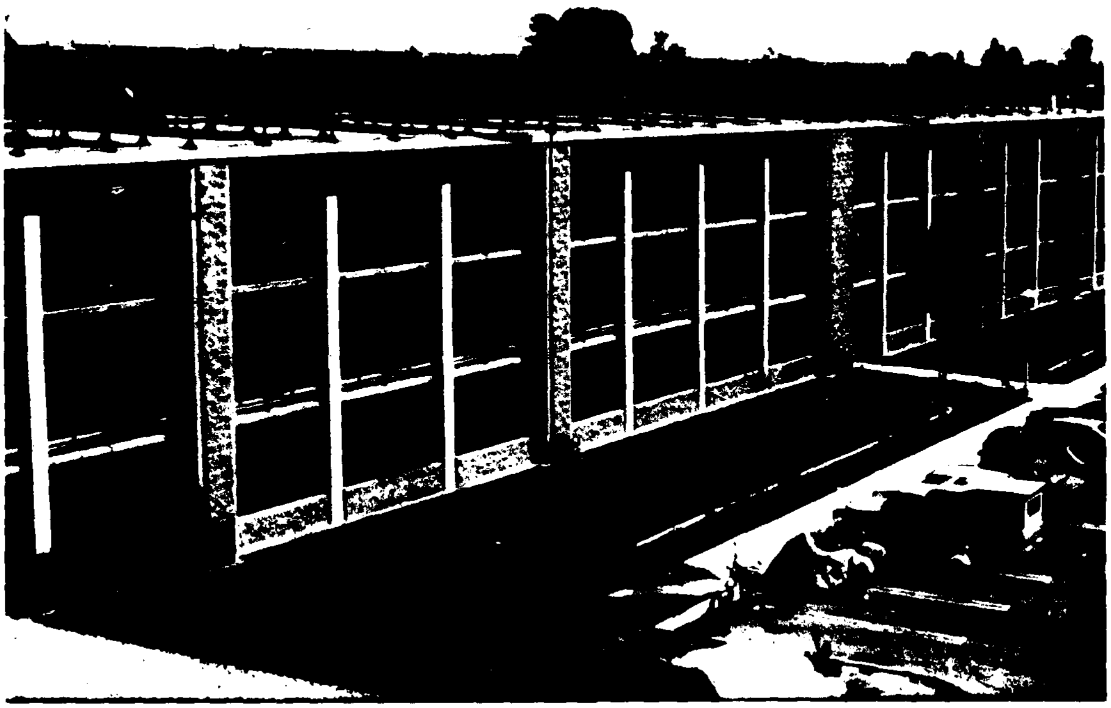

Figure 12. BEQ, MCAS El Toro, Calif.

RESULTS OF SITE EVALUATIONS - ARMY

The U.S. Army has also completed an assessment of operational experiences from 30 of its active solar thermal energy systems. Their evaluations were conducted in the same manner as the Navy and used the same inspection team from LANL. In the course of their evaluations, the Army identified 86 separate problems that are summarized in the five categories as follows:

Problem Description	Frequency
Improper Design	44 (51.2%)
Inadequate Specification	5 (5.8%)
Equipment Malfunction	17 (19.8%)
Improper Operation	13 (15.1%)
Installation Error	7 (8.1%)

The Army has summarized their experiences in one-page sheets similar to the Navy as shown in Summary Sheets 1 thru 11. In the interest of preserving the historical data of this study and still not produce unnecessary voluminous material, the following will be presented. The list of 30 Army sites evaluated is given to document where and what kind of systems are installed. Following the list will be 12 Summary Sheets (12 thru 23) selected from the 30 Army sites to give a point of comparison for some of the problems found. If a particular site is of interest to the reader and not presented in this report, the reader can contact either the author at NCEL ((805) 982-4207, FTS 799-4207) or the Army point of contact, David Joncich ((217) 373-7281, FTS 958-7281) at Construction Engineering Research Laboratory (CERL).

Location	Facility	Solar System	Summary Sheet
FT. Polk, La.	260 Family Housing Units	DHW - Flat Plate Collectors	N/A
FT. Polk, La.	Dining and Barracks Complex	DHW - Flat Plate Collectors	12
FT. Polk, La.	Hospital	SH and DHW - Evacuated Tube Collectors	N/A
FT. Polk, La.	40 Family Housing Units	SH, SC - Evacuated Tube Collectors Central Array	N/A
FT. Polk, La.	Post Exchange	SH, DHW - Evacuated Tube Collectors	13
FT. Benning, Ga.	Armor Tank and Mechanical Shop	DHW - Flat Plate	N/A

Location	Facility	Solar System	Summary Sheet
FT. Benning, Ga.	Barracks	DHW - Shallow Solar Pond	N/A
Yuma Proving Ground, Ariz.	Range Operations Center	DHW, SH, SC - Concentrating Collectors	14
FT. Huachuca, Ariz.	Academic Bldg.	DHW, SH, SC - Concentrating Collectors	N/A
FT. Huachuca, Ariz.	Barnes Field House	DHW - Flat Plate	15
FT. Huachuca, Ariz.	Barnes Field House	Unglazed Flat Plate Collectors for Pool	16
Seagoville, Tex.	Reserve Center	DHW, SH, SC - Flat Plate	N/A
FT. Stewart, Ga.	132 Family Housing Units	DHW, SH - Flat Plate	17
FT. Stewart, Ga.	Dining Hall	DHW - Flat Plate	N/A
FT. Bragg, Calif.	Barracks, Dining Hall	DHW - Flat Plate	18
FT. Bragg, Calif.	Dining Hall	DHW - Flat Plate	N/A
FT. Bragg, Calif.	New Construction Bldg.	DHW, SH - Flat Plate	N/A
FT. Hood, Tex.	Darnell Army Hospital	DHW - Flat Plate	19
FT. Hood, Tex.	Dental Clinic	DHW, SH, SC - Parabolic Concentrating Collectors	20
FT. Hood, Tex.	Enlisted Barracks (BEQ)	DHW - Flat Plate	N/A
FT. Hood, Tex.	Battalion Headquarters	SH, SC - Flat Plate	N/A
FT. Belvoir, Va.	Kingman Building	DHW, SH, SC - Evacuated Tube Collectors	N/A
FT. Riley, Kans.	BEQ	DHW - Flat Plate	21
FT. Ord, Calif.	Housing Units	DHW - Flat Plate	22
FT. Ord, Calif.	Security & Cryptography Building	DHW - Flat Plate	N/A
FT. Ord, Calif.	Dining Hall	DHW - Flat Plate	N/A
Norfolk, Va.	Multipurpose Building	DHW, SH, SC - Evacuated Tube Collectors	N/A

Location	Facility	Solar System	Summary Sheet
Greenwood, Miss.	Army Reserve Center	DHW, SH, SC - Flat Plate	N/A
Albuquerque, N.Mex.	Administration Building	DHW, SH, SC - Flat Plate	23
FT. Bliss, Tex.	Medical Center	DHW - Flat Plate	N/A

DHW = Domestic Hot Water
SH = Space Heating
SC = Space Cooling

SUMMARY SHEET 12
SITE EVALUATION FOR BARRACKS COMPLEX, FT. POLK, LA.

SYSTEM DESCRIPTION

This installation is a dining and barracks complex that has 4,386 ft^2 of flat plate solar collectors and 6,000 gallons storage volume. The load is domestic hot water.

HIGHLIGHTS OF EVALUATION

1. High temperature, UV solar radiation, and trapped moisture has caused the absorber paint to be defective.

2. The solar loop had a faulty controller causing the system to run continuously.

3. The controls malfunctioned so that only one of two storage tanks received solar heat. This was due to system complexity.

4. The undergound tank insulation is rapidly becoming ineffective due to moisture buildup. NCEL has already recommended that buried tanks be avoided.

SUMMARY SHEET 13
SITE EVALUATION FOR POST EXCHANGE, FT. POLK, LA.

SYSTEM DESCRIPTION

The solar system consists of 11,700 ft^2 of evacuated tube solar collectors and 100,000 gallons of storage. Space heating and domestic hot water are supplied to the post exchange building.

HIGHLIGHTS OF EVALUATION

1. A faulty controller caused the heat transfer loop to run continuously.

2. The glycol solution was low at about 16%.

3. A tank of about 20,000 gallons should be added for chilled water storage.

4. The collector array is too small (about half the area than needed) to run the chiller effectively.

5. The solar system piping was routed so that the domestic hot water heat exchanger was after the backup boiler. Hence no solar domestic hot water was being provided. The piping needs to be rerouted.

SUMMARY SHEET 14
SITE EVALUATION FOR YUMA PROVING GROUND, ARIZ.

SYSTEM DESCRIPTION

The solar system consists of 13,000 ft^2 of concentrating collectors and 12,000 gallons storage. It provides domestic hot water, space heating, and space cooling for the range operations center.

HIGHLIGHTS OF EVALUATION

1. There was severe pipe corrosion in the underground piping caused by moisture retention in the pipe insulation. The insulation was the wrong type (open cell) and needs to be replaced with the closed cell type that will not retain moisture.

2. There was not an adequate thermal expansion design causing some damage.

3. The collector loop flowrate was too high.

SUMMARY SHEET 15
SITE EVALUATION FOR FT. HUACHUCA, ARIZ.

SYSTEM DESCRIPTION

The drainback solar system is a 900 ft^2 flat plate array to provide domestic hot water to the Barnes Field House.

HIGHLIGHTS OF EVALUATION

1. The system is operational and performing fine.

2. There was some corrosion in the system. The bicarbonate in the water decomposed and combined with other metals and minerals to form scale. A nontoxic scale inhibitor should be used. No immediate changes are planned. This is not untypical of systems in which the collector loop fluid is not regularly changed and the long term effects are unknown.

SUMMARY SHEET 16
SITE EVALUATION FOR SWIMMING POOL, FT. HUACHUCA, ARIZ.

SYSTEM DESCRIPTION

The solar system consists of 2,000 ft^2 of unglazed flat plate collectors to supply pool heating.

HIGHLIGHT OF EVALUATION

1. The system is operational and performing satisfactorily.

2. The copper tubing of th. collectors may be corroded in the future by the chlorine in the pool water. Nonmetallic collectors are usually used for pool heating.

SUMMARY SHEET 17
SITE EVALUATION FOR FT. STEWART, GA.

SYSTEM DESCRIPTION

These solar systems provide domestic hot water and space heating for 132 family housing units. Each housing unit has 80 ft^2 of flat plate collectors and a 120-gallon storage tank.

HIGHLIGHTS OF EVALUATION

1. There was some loss of heat through the top of the tanks which were poorly insulated. More insulation was recommended.

SUMMARY SHEET 18
SITE EVALUATION FOR FT. BRAGG, CALIF.

SYSTEM DESCRIPTION

The solar system is a 1,950 ft^2 flat plate collector system that feeds 4,000 gallons storage volume. It provides domestic hot water for a barracks/mess hall complex.

HIGHLIGHTS OF EVALUATION

1. *The system experienced some freeze problems.* The controller logic called for the collector loop to turn on when there was a 4°F temperature differential across the array. This allowed the glycol to circulate below 32°F. The short term solution was to install a snap switch sensor that will prevent circulation below 42°F. The long term solution is to use a differential controller between the solar collectors and tank. This should have been done in the original design.

SUMMARY SHEET 19
SITE EVALUATION FOR HOSPITAL, FT. HOOD, TEX.

SYSTEM DESCRIPTION

The solar system provides domestic hot water for the Darnell Army Hospital. The system has 4,300 ft^2 of flat plate collectors and 7,560 gallons of storage.

HIGHLIGHTS OF EVALUATION

1. Moderate to high winds can lift the manifold pipes off their rollers. They need to be tied down.

2. Pipe insulation was wet, caused by water seeping through cracks in the coated fabric on the pipe insulation jacket.

3. The collector flowrate needed to be adjusted.

4. There were overly complex controls on the collector to storage and storage to load loops.

5. Silicone rubber hose and hose clamps are used on the collector connections. These may leak in the future.

6. The overall control logic was too complex. There was no O&M manual to aid with this complex logic.

7. The level of corrosion inhibitor in the solar collector loop was low.

SUMMARY SHEET 20
SITE EVALUATION FOR DENTAL CLINIC, FT. HOOD, TEX.

SYSTEM DESCRIPTION

The solar system provides domestic hot water, space heating, and space cooling for a dental clinic. The system uses 4,394 ft^2 of concentrating parabolic solar collectors and 8,500 gallons storage.

HIGHLIGHTS OF EVALUATION

1. There was some degradation (discoloration) present on several of the receiver tube selective surfaces. The cause was not known.

2. There was some control logic error that didn't allow the maximum energy delivery to the heat exchanger.

SUMMARY SHEET 21
SITE EVALUATION FOR FT. RILEY, KANS.

SYSTEM DESCRIPTION

The solar system provides domestic hot water for a barracks (BEQ) and uses 2,700 ft^2 of flat plate collectors to charge a 6,200-gallon storage tank.

HIGHLIGHTS OF EVALUATION

1. There were leaks caused by water boiling when the collector loop stagnated. The leaks occurred at the system weak point of the hose connection from the collector to the return line. The solution was to install air vents at each collector bank.

2. The control system was overly complex.

3. There was some scale buildup in the system due to the local "hard" water. The system may need to be flushed and inhibited propylene glycol used.

SUMMARY SHEET 22
SITE EVALUATION FOR FT. ORD, CALIF.

SYSTEM DESCRIPTION

This solar system provides domestic hot water to family housing units. Each unit has a 192 ft^2 flat plate solar system and a 240-gallon storage tank.

HIGHLIGHTS OF EVALUATION

1. There was some tank corrosion caused by leaking solder joints. This was an installation error never fixed by the contractor.

2. Flow rates through the heat exchanger are not matched resulting in poor heat exchange.

3. Some pitting was noticed in copper pipe caused by the high chloride content in water.

4. The collector array is too small or the storage too large. The proper range is 1.8 to 2.0 gallon per ft^2 of collector. The present system is:

$$\frac{240 \text{ gal}}{192 \text{ ft}^2} = 1.25 \text{ gal/ft}^2$$

5. This system used silicone oil, which probably caused problems No. 1 and No. 2. Silicone oil is difficult to seal, and the difference in density with water will give different flow rates. This needs to be considered in original designs when used.

SUMMARY SHEET 23
SITE EVALUATION FOR ALBUQUERQUE, N.MEX.

SYSTEM DESCRIPTION

The solar system provides domestic hot water, space heating, and space cooling to an administration building. The system uses 10,600 ft^2 of flat plate collectors and 20,000 gallons storage.

HIGHLIGHTS OF EVALUATION

1. The solar controller is interfaced with the EMCS system causing unreliable operation. It should be replaced with a stand alone electronic solar control unit.

2. The absorption chiller unit was not functioning causing an excess of collected energy. This energy could be rejected by running the system at night or covering the collectors during the day.

3. There were some leaks at the dielectric couplers which were of a poor design.

RESULTS OF SITE EVALUATION - AIR FORCE

The Air Force also participated in this tri-service effort by providing 11 sites for evaluation. Their evaluations were also conducted in the same manner as the Navy and the Army. The Air Force has not provided one-page summaries of the evaluations, but has provided the LANL report of each site. From these reports the author has compiled the following list for the problem categories:

Problem Description	Frequency
Improper Design	15 (38.5%)
Inadequate Specification	5 (12.8%)
Equipment Malfunction	12 (30.8%)
Improper Operation	6 (15.4%)
Installation Error	1 (2.5%)

As was done previously, the Air Force's experiences are summarized by listing the sites evaluated, followed by Summary Sheets of six of the 11 sites (24 thru 29). If further information is desired on any site, the reader can contact the author or the Air Force point of contact: Air Force Engineering and Services Center, TYNDAL AFB, FLA., Mike Santoro (904) 283-6459, A/V 970-6459.

Location	Facility	Solar System	Summary Sheet
Nellis AFB, Nev.	BOQ	DHW, SH - Flat Plate	N/A
Sheppard AFB, Tex.	Family Housing Units	DHW, SH - Flat Plate	N/A
Robins AFB, Ga.	Corrosion Control Bldg.	DHW - Flat Plate	24
Edwards AFB, Calif.	Airmen's Dormitory	DHW - Flat Plate	N/A
Edwards AFB, Calif.	Library	DHW, SH - Flat Plate	25
Eglin AFB, Fla.	Airmens Dormitory and Building 1	DHW - Flat Plate	26
Norton AFB, Calif.	Aerospace Audio-Visual Building	DHW, SH - Flat Plate	N/A
Griffis AFB, N.Y.	Base Fire Station	DHW - Flat Plate	27
Mountain Home AFB, Idaho	Bldg. 4809 of Base Housing Complex	DHW - Flat Plate	28
U.S. Air Force Academy, Colo.	Academy Youth Center, Bldg. 5132	SH - Flat Plate (Air type)	29
Mather AFB, Calif.	Personnel Building	DHW, SH - Flat Plate	N/A

SUMMARY SHEET 24
SITE EVALUATION FOR ROBINS AFB, GA.

SYSTEM DESCRIPTION

The solar system provides hot water for use in a paint stripping and etching process that provides corrosion control for aircraft. The system consists of 18,000 ft^2 of flat plate collectors and a 125,000-gallon storage tank.

HIGHLIGHTS OF EVALUATION

1. A change in control strategy was recommended that would let the collectors heat only a portion of the 125,000-gallon tank capacity (about 35,000 gallons) at a time. This would raise the end use temperature from about 80 to 100°F to 120°F or higher. This is a better temperature for this process.

2. The system was computer controlled which, for various reasons, resulted in less than optimum performance. It was recommended that it be replaced with a differential temperature controller.

SUMMARY SHEET 25
SITE EVALUATION FOR EDWARDS AFB, CALIF.

SYSTEM DESCRIPTION

This flat plate collector system provides domestic hot water and space heat for a library through a 500-gallon storage tank.

HIGHLIGHTS OF EVALUATION

1. The system was operational at the time of evaluation. Several improvements were suggested.

2. Two changes were suggested to improve collector performance:

   a. Turn backup boiler operating temperature down to 110°F (from 135°F).

   b. Relocate the collector sensor from the return header to the outlet of a collector. This will prevent the sensor from lagging the true collector temperature by 30 to 50°F.

3. Change collector piping to give a reverse-return flow pattern.

4. Add glycol to collector loop to bring it up to 30 to 50% solution.

SUMMARY SHEET 26
SITE EVALUATION FOR EGLIN AFB, FLA.

SYSTEM DESCRIPTION

The solar systems operate on two buildings. Building 1 has 200 ft^2 of flat plate collectors and a 500-gallon storage tank. Building 200 (Airmen's dormitory) has two identical units, each utilizing 1,500 ft^2 of flat plate collector and 1,750 gallons storage.

HIGHLIGHTS OF EVALUATION

1. Building 1

   a. The system was operational at the time of evaluation.

   b. One collector was leaking due to a freeze sensor not being located properly.

   c. The collector sensor should be relocated from return manifold to collector outlet.

   d. The plumbing should be changed to reverse return or valves added for proper flow balance.

2. Building 200

   a. One freeze thermostat had failed.

   b. A motor relay or motor problem prevented one system from operating.

   c. A change should be made to reverse-return piping or add flow balancing valves.

   d. The collector mounting rack is made of wood which is generally not a good idea.

SUMMARY SHEET 27
SITE EVALUATION FOR GRIFFIS AFB, N.Y.

SYSTEM DESCRIPTION

The solar system provides domestic hot water to the base fire station. The system uses 28 flat plate collectors, ground mounted in two rows on the east side of the fire station. There is a 865-gallon storage tank connected to a 120-gallon domestic hot water heater.

HIGHLIGHTS OF EVALUATION

1. The existing controls, a contractor designed item, did not appear to be working. It was recommended that they be replaced with a good quality, solid state differential controller (approximate cost of $100).

2. There was a problem with the solar loop pump not operating properly.

3. Indoor pipe insulation was used outdoors and is deteriorating.

4. The domestic hot water heater should be reset to 120°F (vice 170°F) for better system operation.

5. There was no O&M manual even though it was required by the project specification.

SUMMARY SHEET 28
SITE EVALUATION FOR MOUNTAIN HOME AFB, IDAHO

SYSTEM DESCRIPTION

The solar energy system provides domestic hot water to Building 4809 of the Base Housing Complex. It uses 13 flat plate collectors and three 120-gallon storage tanks.

HIGHLIGHTS OF EVALUATION

1. Overall, the system appeared well designed and is functioning properly. There were two minor problems.

2. The storage-temperature sensor should be relocated from the hot water supply line to the storage tank itself or as close as practical.

3. Some degraded pipe insulation should be replaced.

SUMMARY SHEET 29
SITE EVALUATION FOR U.S. AIR FORCE ACADEMY, COLO.

SYSTEM DESCRIPTION

The Air Force Academy solar system provides space heating for the Youth Center Building 5132. The system uses five different models of air-type collectors (air is the working fluid).

- SOLARON Model 2001 (16 each)
- SOLARON Model 2003-X (10 each)
- SOLARON Model 2003-Y (10 each)
- ROM-AIRE Model EF-212 (32 each)
- ROM-AIRE Model E-48 (21 each)

The total collector area is approximately 1,800 ft^2. The solar system is connected to the building heating system by the supply and return air ducts.

HIGHLIGHTS OF EVALUATION

1. Overall, the system is in good operating condition. There were three minor problems.

2. There were two suggestions made to enhance the control strategy. One suggestion involved moving one sensor, and the other changed the controller delta from 8°F on/3°F off to 20°F on/5°F off. These were more "tune up" type changes.

3. Some loose metal cap strips on the ROM-AIRE collectors should be reattached. This can be done with metal self-tapping screws and sealed with silicone sealant.

4. A tree should be removed or trimmed so that it does not shade the north bank solar array.

SUMMARY SHEET REVIEW

The purpose of the preceeding solar system evaluations is to gain insight on past designs with the intent to improve future designs and to insure a long solar system life. To do this, it is necessary and instructive to list and categorize past errors.

The experiences of each military service are similar in problems found. All seemed to agree that the biggest problem categories are improper design and equipment malfunction. The latter category is not unexpected in a new energy industry and strides are being made by manufacturers and installers to improve equipment life. Most of the systems evaluated are old designs and in many cases represent the early equipment on the market.

The former category of "improper design" showed up in each service evaluation. The third most frequent occurrence was "improper operation," which covered a variety of ills from occupant tampering to lack of maintenance allowing a system to run dry. The Army had more instances of bad design but they also had more intallations and also tried to do more sophisticated designs such as solar cooling. Other than that, the record of each is similar and points to a few common errors where improvements are needed.

1. The most common failure is the control system including the sensors, controller, and pump, usually in that order of frequency.

2. The contractor should provide adequate drawings, a system operations manual, and a maintenance guide.

3. The occupants should be discouraged from tampering with system by the use of signs, brochures, etc. They should be encouraged to report problems.

4. Systems that use glycol in the solar loop seem more susceptible to leaks and should be checked accordingly. Glycol systems should have the pH checked annually and results marked conspicuously on or near the system. If pH is below 6.5 the glycol should be replaced. There are gages that automatically indicate glycol charge. Provide taps to take samples.

5. Label all heat transfer fluids used other than water.

6. While excessive instrumentation is not encouraged, if budget permits, thermometers should be installed on either collector outlet or storage tank, or both. On large systems, this is an incidental cost and should be mandatory.

These specific items have already been reported and field activities alerted by NCEL Tech Data Sheet 84-12 (Ref 2). The results of these Summary Sheets have not changed these indications and, in fact, most of the "lessons learned" of Reference 2 already encompass the items found by the individual services.

The main conclusion of Army researchers is that the Army has too many one-of-a-kind systems and that they are overly complex in design.

The intent is to use this data base of lessons learned to impact the Navy's Military Handbook (Ref 4) and other reports as appropriate. A computer system is being developed at NCEL that will serve as an expert solar repairman to aid field personnel in troubleshooting and fixing solar systems. The work done here provides the baseline for the "expert" systems.

The Army is developing a guide specification and technical manual through which the results of this effort and other work will be transmitted to field activities. The Army effort is scheduled for completion in FY87. These reports will contain the following areas:

a. Feasibility Assessment - A user friendly computer program (SOLFEAS) using an interactive time-share computer to assess feasibility (see Ref 5 for more such programs).

b. System Selection - Provides for the selection of standard system designs to reduce the number and complexity of systems.

c. System Design - Provides sizing and design of systems to avoid problems as seen in the past.

d. Acceptance Criteria - Insures that installed systems comply with design specifications.

e. Operations and Maintenance - Gives criteria to operate and maintain systems in the best way.

The culmination of all these efforts including the Navy documents already published (Refs 1 through 4) and the Army efforts will provide a series of powerful tools that will provide a means to have simpler, more reliable, longer lived solar systems to meet the needs of the military services.

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4. Military Handbook (MIL-HDBK) 1003/13A, "Solar heating of buildings and domestic hot water." 14 Jun 1985.

5. Naval Civil Engineering Laboratory. Technical Data Sheet 85-25: Computer programs that calculate solar energy systems performance, by E.R. Durlak. Port Hueneme, Calif., Nov 1985.

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