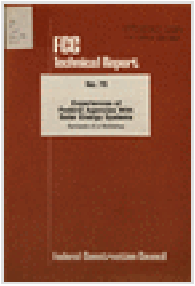

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Technical Report

No. 79

Experiences of Federal Agencies With Solar Energy Systems

Synopsis of a Workshop

Federal Construction Council
Consulting Committee on Mechanical Engineering

NATIONAL ACADEMY PRESS
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1985

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PREFACE

During the past decade, federal agencies have both installed and funded the installation of hundreds of active and passive solar energy systems to heat and cool buildings and to heat water for domestic use. As a result, the agencies have acquired considerable data and experience concerning the performance of such systems that could be of value to designers and users of future systems. Some of this information has been published and some has not. In order to provide federal agency personnel with an opportunity to become better informed about the design and operation of solar energy systems, the Federal Construction Council (FCC) Program Committee asked the FCC Consulting Committee on Mechanical Engineering to arrange a workshop on the subject.

The workshop was held at the National Bureau of Standards (NBS) on May 8, 1984, as part of the Federal Workshop Series for 1984 of the NBS Center for Building Technology. Eleven presentations were made by representatives of ten federal agencies. The speakers were asked to prepare summaries of their remarks and it is these summaries that comprise this report. The speakers were given no precise specifications regarding summary format; therefore, the summaries vary in length and form.

CONTENTS

LESSONS LEARNED FROM THE HUD SOLAR DEMONSTRATION PROGRAM

David C. Moore
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INTRODUCTION

Under the authorization of the Solar Heating and Cooling Demonstration Act of 1974 (P.L.93-409), the Department of Housing and Urban Development (HUD) conducted a residential solar heating and cooling demonstration program as part of the national solar energy program from 1975 to 1982. The original intent of the program was to help bring the nascent solar industry to the point that it could economically serve the housing industry with efficient and cost-effective heating and cooling equipment.

The HUD program had four main elements: demonstrations of solar systems in residences, the development of standards for the industry, studies of market constraints and ways to overcome them, and establishment of a national information program on solar heating and cooling. This discussion is concerned only with the demonstration activities and findings.

DEMONSTRATION PROGRAM

The demonstration program had three objectives: to involve homebuilders early in working with solar energy, to obtain information on performance and market acceptance, and to provide examples of solar installations for the public to see. Projects were selected competitively. In eight national solicitations, HUD evaluated 3,837 applications, awarded 943 grants (including some which were for design-only projects), and watched 497 projects get built. In all, 1,255 solar systems provided hot water, space heating, or space cooling to 10,098 dwelling units. The first awards, in 1976, were primarily for active space and water heating in single family units; by 1978, most of the awards were for large water heating systems in multifamily units; and in 1978 and 1979, the final awards were for passive solar homes and passive retrofit installations in multifamily buildings.

DEMONSTRATION EXPERIENCE

The program goals as stated in P.L.93-409 were "to provide for the demonstration within a three-year period of the practical use of solar heating technology and to provide for the development and demonstration within a five-year period of the practical use of combined heating and cooling technology." The demonstration projects showed that these goals were overly ambitious, given the state of the industry and of the art of solar design and installation. Although the program showed that active solar space heating was possible, it was difficult to achieve and comparatively expensive. Passive solar space heating, on the other hand, proved to be practical, attractive, and economical. Surveys of owners of the passive solar homes almost invariably showed a continuing satisfaction with the homes. Solar domestic water heating also proved to be practical and, when compared with electric water heating, generally economically feasible. Solar space cooling was extremely expensive and difficult to keep operating; in fact, none of the demonstration units worked satisfactorily.

PROBLEMS AND THE REPAIR PROGRAM

System problems developed early in the overall program--originally from poor installation, inadequate design, and, occasionally, inappropriate equipment. In 1978, however, a new type of problem, endemic to specific system types, began to occur. Three separate groups of problem systems were identified: systems with wood components that presented a fire hazard, liquid space heating systems in which corrosion developed on the non-solar or service side, and passive homes with inadequate provisions for controlling overheating or night-time losses. In all, 599 (48 percent) of the active systems in the program were involved in the repair or removal program (and, it must be noted, not all of the 1,255 systems were inspected).

FIRE HAZARD

In 1980, a stagnating flat plate collector caused a roof fire in a residence in Boulder, Colorado. Examination of this incident led to an intensive review of all projects in which wood materials were exposed to elevated temperatures and a determination that any such system had to be designed and installed so that the wood materials were not exposed to temperatures over 150°F for extended periods.

SERVICE-SIDE CORROSION

The potential problem of solar loop corrosion was recognized from the beginning, and most systems were designed to control this corrosion or to minimize it through adequate maintenance. However, without exception, the liquid space heating systems in the HUD program developed serious corrosion in the non-solar or service side. These systems had been designed using good hydronic heating system practice but without the recognition of the fact that the presence of solar storage tanks vented to the atmosphere provided a continual replacement of oxygen in the circulating water--something not possible in a sealed and pressurized hydronic loop. This additional oxygen permitted corrosion to develop at all the interfaces between dissimilar metals typically found in hydronic systems. Repairs involved either replacement of all non-cupric components or the closing and pressurization of the systems.

PASSIVE CONTROL

Passive systems that did not provide for control of overheating in the summer or for night-time losses in the winter were common in the early projects. This situation, while not a significant hazard, was irritating to the involved homeowners. It is easy to correct in design and, with some expense, after the home is built, but it needs consideration by the designer and builder.

RECOMMENDATIONS

Based on the experience gained during the HUD demonstration program (and not reflecting any changes made in the industry's capability since 1982), the following recommendations have been made:

1. Solar domestic hot water (DHW) systems are practical when well installed and carefully maintained. They can be economically feasible when compared with electric DHW systems, but each installation should be evaluated on the basis of its cost, its performance, and the comparison of its value with conventional DHW systems.
2. Passive solar space heating (and cooling through ventilation) can be provided in most new housing with careful design and good energy-conserving construction. In the HUD demonstration homes, owners in general were very pleased with the performance of their homes and with the savings in energy costs.
3. Active space heating and cooling systems are generally expensive, require significant maintenance efforts, and are subject to serious problems of installation quality control. Although the HUD demonstrations often were repaired to working condition, the total cost of these systems generally provedto be uneconomic except in special situations.

ADDITIONAL DOCUMENTATION

A Final Report of the Management Support Contractor for the Residential Solar Heating Demonstration was prepared in June 1983 by BE&C Engineers, Inc. This five-volume document focuses on: Management Support Activity (Report HUD-000-3095/PB-84-188507), Solar Repair Program (Report HUD-000-3096/PB-84-188515), High-Temperature Exposure of Wood Structures (Report HUD-000-3097/PB-84-188503), Corrosion Problems (Report HUD-000-3098/PB-84-208214), and Summary of Data Findings (Report HUD-000-3099/PB-84-208222). These documents are available from HUD USER (PO Box 280, Germantown, MD 20874--301/251-5154) or the National Technical Information Service.

PERFORMANCE OF HUD PASSIVE SOLAR DEMONSTRATION HOMES

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INTRODUCTION

Under the solar demonstration program of the Department of Housing and Urban Development (HUD), 1,255 solar systems were constructed, 266 of which were passive solar systems. Each received a HUD grant averaging between $10,000 and $12,000. The last grant was made in 1979. Twelve of the 266 systems were instrumented and reported on by the National Solar Data Network (NSDN). The elements of a passive solar system are described below as are the characteristics and performance of 11 of the 12 passive systems for which data are available.

PASSIVE SYSTEM ELEMENTS

All true passive systems should include and can be recognized by five clearly defined elements. These are: collector, absorber, storage, distribution, and control (or heat regulation device).

Collector refers to the glazing through which solar radiation enters the house (Figure 1). The primary collector(s) should face within 30 degrees of true--not magnetic--south and should not be shaded throughout the heating season during the peak solar collection period between 9 a.m. and 3 p.m. The area of the collector determines how much of the available direct solar radiation the house has the potential to collect. The performance of the collector can be enhanced by directing additional sunlight towards it from a reflective surface.

Absorber refers, in most passive solar systems, to the hard, darkened surface of the storage elements (Figure 2). This surface--which could be that of a masonry wall, floor, or room divider or that of a water container--sits in the direct path of solar radiation. It intercepts the sunlight, which then degrades to heat that is absorbed by the surface.

Storage refers to the materials used in the construction of the house that are specifically intended to hold the heat produced by sunlight (Figure 2). These materials are sometimes called "thermal mass" and they are usually either masonry (concrete, concrete block, or brick) or water. The difference between the absorber and storage, although they are often the same wall or floor, is that the absorber is an exposed surface whereas storage is the material below or behind that surface.

Distribution refers to the method by which solar heat is circulated from the collection and storage points to different areas of the house (Figure 3). A strictly passive design will use the three natural heat transfer modes--conduction, convection, and radiation--exclusively. This type of distribution requires a house plan that encourages the formation of natural convective flows. The careful layout of interior spaces will allow heat to circulate from the collection and storage points to where it is needed throughout the day and night. It is, however, often desirable to give mechanical assistance to distribution in the form of fans and blowers and to provide ductwork to carry heat from one area of the house to another.

Control or heat regulation device refers to those elements that prevent under- or over-heating and heat loss (Figure 4). This includes moveable insulation that is placed over the inside of the collector area on winter nights to control heat loss. Conversely, moveable insulation also can be used on summer days to control overheating by keeping sunlight out of the house. Control devices also may include electronic sensing devices such as differential thermostats that signal a fan to turn on, operable vents and dampers that allow or restrict heat flow, and roof overhangs or awnings that shade the collector area during summer months.

FIGURE 1 Collector

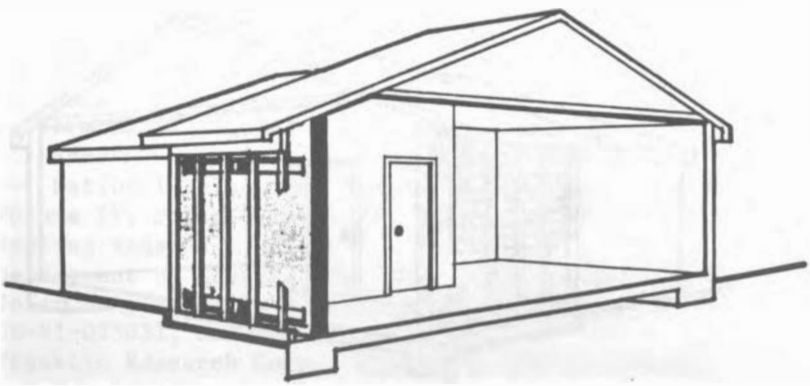

FIGURE 2 Absorber/Storage

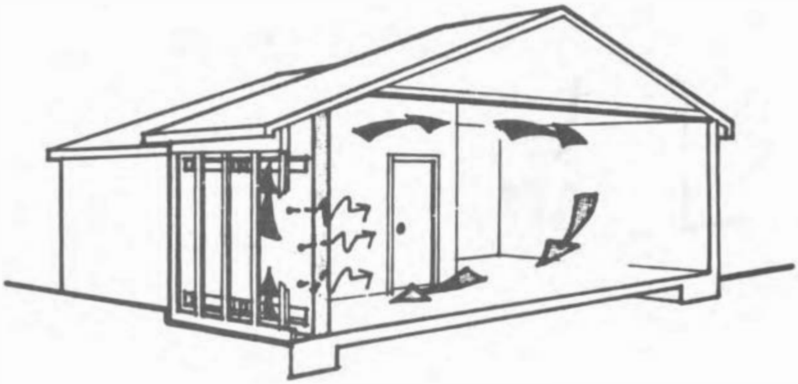

FIGURE 3 Distribution

FIGURE 4 Control (heat regulation device)

RESULTS

Information on the nature and performance of the 11 instrumented passive systems for which HUD provided grants is presented in Table 1. Some systems did not perform well for various reasons (e.g., insufficient storage, inadequate insulation, and improper orientation). However, the systems were innovative prototypes and failures were anticipated. In general, the program results indicated that overly elaborate systems do not work, that conservation actions must be taken before passive solar systems are installed, and that a passive solar system will add $3,000 to $5,000 to the cost of a house containing between 2,000 and 2,500 square feet.

SOURCES OF ADDITIONAL INFORMATION

More information on the HUD program can be obtained from the following reports, all of which are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4600.

1. Vitro Corp. Availability of Solar Energy Reports from the National Solar Data Program, Solar/0020-83/43, January 1983
2. -- Comparative Report: Performance of Passive Solar Space Heating Systems in the National Solar Data Network
    a. Solar/0022-79/39, July 1979, 1978-79 Heating Season
    b. Solar/0022-81/39, January 1981, 1979-80 Heating Season
    c. Solar/0022-82/39, June 1982, 1980-81 Heating Season
3. -- National Solar Data Program Performance Results, Volume IV, Solar/0005-81/82, 1979-80 and 1980-81 Heating Seasons
4. Department of Energy. New Energy-Conserving Passive Solar Single-Family Homes, Cycle 5, Category 2, DE-81-025031, January 1981
5. Franklin Research Corp. Proceedings of the Passive and Hybrid Solar Energy Update, Conf.-820940, November 1982, 1981-82 Heating Season, p. 207

TABLE 1 Project Data

Project	Location	Floor Area (sq ft)	Collector Type	Collector Area (sq ft)	Absorber/Storage
Greenmoss	Vermont	800	Sunspace	278	Block wall
John Byram	Kansas	1675	Sunspace	NI[a]	16 in. concrete floor Brick wall
Hullco	Arizona	1056	Sunspace	424	12 in. concrete wall 4 in. concrete floor 670 cu. ft. rock bin
Colorado Sunworks	Colorado	1792	Mass wall Skylights	350 30	52-55 gal drums 4 in. concrete floor
Living Systems	California	1671	Mass wall & direct gain Clerestory	192 81	3343 gal in steel tubes 6 in. concrete floor
Werner, et al	Iowa	2128	Direct gain (double wall)	277	1040 gal in tubes 8 in. concrete slab
Gill Harrop	New York	1231	Direct gain Clerestory	305 98	6 in. concrete floor 8 in. concrete walls
Environ-mental	New Jersey	1655	Mass wall Direct gain	344 168	50000 lb concrete block wall 32 thermal rods
Baker	Ohio	1600	Sunspace with tilted glazing	302	12 in. concrete wall Floor slab Thermal rods
Arno Kahn	Minnesota	1428	Sunspace Direct gain	440 100	68000 lb sand-filled concrete block wall
Modena	Oregon	1492	Mass wall Clerestory	110 37	18-55 gal water drums 4 in. concrete floor

[a]NI means not indicated.
[b]Installation of curtains has not been verified.
[c]Storage capacity factor is calculated by dividing the storage capacity, in Btu, by the product of the collector area, in sq. ft. times the temperature rise, in F, in the storage medium.
[d]System efficiency is calculated by dividing the amount of heat used to meet heating needs by the total available solar heat.
[e]Solar fraction is the percentage of the heating load in a building that is satisfied by the solar system.

Distribution	Control Mechanism	Collector Area to Floor Area Ratio	Storage Factor[c] (Btu/sq ft F)	System Efficiency[d] (%)	Solar Fraction[e] (%)
Radiation Cavity to duct	Exhaust fan Curtains[b]	0.35	36	NI	NI
Windows Fans	Shades Trees	NI	NI	44	42
Radiation	Venting Trees Snow fence	0.38	43	58	76
Convection Radiation	Beadwall Overhang	0.21	83	34	65
Radiation	Insulating curtains Foam panels Overhang	0.16	100	34	62
Radiation	Insulating curtains Overhang	0.13	111	23	16
Radiation	Moveable quilt-type insulation	0.30	45	48	84
Radiation	Curtains Operable windows	0.37	30	NI	34
Fan assist	Moveable insulating shades	0.25	62	25	37
Double envelope convection loop	Insulating curtains Overhang Operable windows	0.20	77	44	43
Convection Radiation	Insulating shutters Overhang	0.10	125	28	16

THE EXPERIENCE OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WITH SOLAR ENERGY SYSTEMS

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The National Aeronautics and Space Administration (NASA) is chartered to conduct space and aeronautical activities for peaceful purposes for the benefit of all mankind. Within this context falls expanding man's knowledge of earth, its environment, the solar system, and the universe. For many years, NASA has maintained a comprehensive conservation program committed to the development, demonstration, and use of alternate energy sources primarily for the following objectives:

1. To preserve NASA's mission capability by reducing dependence on fossil fuels.
2. To stimulate growth of alternate energy technologies.
3. To promote awareness of saving conventional fuels.
4. To assist in the national demonstration of alternate energy sources.

The NASA facilities consist of 11 major field installations located throughout the continental United States as well as numerous component facilities and overseas tracking stations. Combined, these facilities represent over 33 million square feet of floor space.

During the 1970s and early 1980s NASA has sponsored or has jointly participated in 29 land-based solar thermal projects. These represent a total collector area of approximately 66,000 square feet at a total installed cost of over $3.5 million. Most of these were part of the Department of Energy's (DOE) Solar in Federal Buildings Demonstration Program or were jointly funded by DOE and NASA. Eight projects, however, were totally funded by NASA.

The NASA publication, Solar Thermal (and Other Alternate/Renewable) Project Experience briefly describes NASA's experiences with 18 of the 29 projects mentioned above as well as its experiences in other alternate energy activities. This document is currently not in stock; however, additional copies are being printed and will be made available soon.

Figure 1 is an illustration from our publication. It is a schematic diagram of the solar system installed at an experimental house constructed at the Langley Research Center in Virginia.

As part of its solar program, NASA collected data on the performance of buildings in which solar systems were installed. Figure 2 summarizes data on electric power consumption before and after installation of a solar system on a photo lab at the Langley Research Center.

Although NASA is no longer actively pursuing the design and installation of conventional solar collection systems, primarily because it has not found them to be cost-effective in terms of NASA's payback criteria of 5

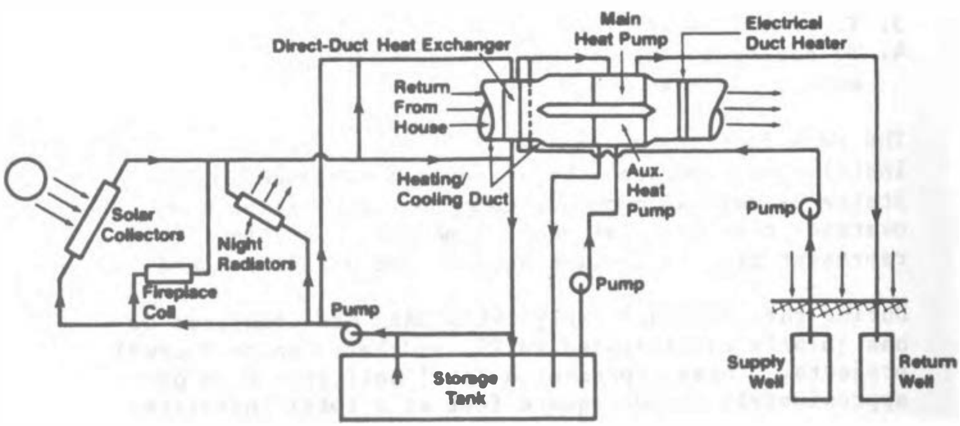


FIGURE 1. System installed at the Langley Research House

years or less, a number of lessons have been learned. In general terms, they can be summarized as follows:

1. Most systems are not cost-effective but offer an alternate to fossile fuel use.
2. Exploration of solar thermal applications has often identified other conventional conservation opportunities.
3. An excellent application exists when solar allows high-heat-loss steam distribution systems to be shut down.
4. Significant amounts of nonrenewable energy can be saved by judicious solar applications.
5. Simple paybacks provide a generally inadequate measure of system cost-effectiveness. Life-cycle costing appears to be a more realistic measure.
6. Hands-on solar system experience at all levels is required for proper applications.
7. System performance cannot be adequately verified without appropriate monitoring.
8. Instantaneous collector efficiency is inadequate for performance prediction. All-day efficiencies should be used.
9. System thermal losses are frequently higher than expected and greater allowances for losses should be made.
10. Collector support structures tend to be overdesigned.
11. Installation requires special care.
12. Systems work and they all save energy.
13. A good maintenance program is essential.

NASA's direction today is primarily oriented toward development of space solar array systems and a continuation of our efforts to make photovoltaics a cost-effective alternate energy source.

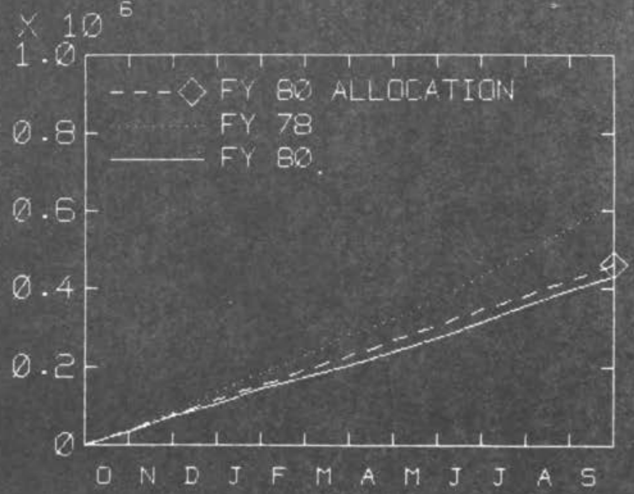
FY 78-80 LRC ELECTRIC POWER USAGE

BLDG. 1155

PHOTOGRAPHIC LABORATORY

(SUM OF METERS -- 189+139)

	FY 78	FY 80
OCT	0.0371	0.0366
NOV	0.0471	0.0379
DEC	0.0505	0.0328
JAN	0.0498	0.0375
FEB	0.0454	0.0314
MAR	0.0523	0.0312
APR	0.0402	0.0347
MAY	0.0497	0.0349
JUN	0.0606	0.0379
JUL	0.0598	0.0428
AUG	0.0662	0.0390
SEP	0.0589	0.0343
TOTAL =	0.6175	0.4312



FY 80 ALLOCATION	=	0.4600
USED FY 78 SAME PERIOD	=	0.6175
BALANCE FOR FY 80	=	0.0288

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FIGURE 2 Example of electric power consumption data collected in the NASA solar program

NATIONAL BUREAU OF STANDARDS PERFORMANCE CRITERIA FOR SOLAR HEATING AND COOLING SYSTEMS

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A major responsibility of the National Bureau of Standards (NBS) under the National Solar Heating and Cooling Demonstration Program (P.L. 93-409) was the preparation of performance criteria for solar heating and cooling systems in residential buildings. The initial performance criteria document was published in January 1975. It was subsequently revised in November 1978 and September 1982. A brief review of the significant revisions made in the various performance criteria areas (i.e., thermal, mechanical, safety and health, durability/reliability, operation and servicing) as a result of solar research and demonstration activities during this 7-year period was presented. Progress made in the development of the American Society for Heating, Refrigerating and Air Conditioning Engineers and the American Society for Testing and Materials standards for active solar systems, components, and materials was also discussed. These standards are referenced in the solar performance criteria documents prepared by NBS for residential buildings (Building Science Series 147, September 1982) and commercial buildings (Technical Note 1187, April 1984).

During August 1983, NBS held two workshops with solar system and controller manufacturers to aid in identifying research priorities for improving the effectiveness of state-of-the-art active solar energy systems. Workshop participants felt that the training of installers and designers was a high-priority need but indicated that such training should be conducted by the solar industry. Identified as recommended research activities that should be supported by the federal government were: controls (control strategies, accepted practices), materials (durability data, test and evaluation procedures), subsystem/component performance data, technology transfer, and design tools (NBS IR 84-2980, December 1984).

Department-of-Energy-sponsored solar energy research being conducted at NBS during FY 1984 was also discussed. In regard to materials, studies are being carried out to: (1) characterize the degradation mechanisms that occur in polymeric cover materials for solar collectors and (2) evaluate the potential of various inorganic compounds for utilization as energy storage media. For components, NBS is continuing research to develop recommended test procedures for measuring the thermal performance of passive solar aperture and storage components. In the systems area, experimental investigations are underway to: (1) quantitatively evaluate the thermal performance of solar domestic hot water systems with reduced flow rates through the collector array and (2) measure the thermal performance of various systems in the NBS Passive Solar Test Facility.

In conclusion, it was suggested that the Federal Construction Guide Specification (FCGS) Section 13980, Supplementary Solar Hot Water and Space Heating Systems, should be revised based on federal agency experience gained in the past several years. NBS had the lead role in preparing the original specification published in September 1981.

LESSONS LEARNED FROM AN ON-SITE EVALUATION OF NAVY SOLAR ENERGY SYSTEMS

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INTRODUCTION

The overall purpose of reduced energy consumption at Navy shore facilities has led to the installation of many solar thermal systems at Navy bases. As solar designs move from theory to practice, a knowledge of reliability, durability, and maintainability is desired to achieve maximum system performance. The Naval Civil Engineering Laboratory (NCEL) has been designated as lead laboratory for investigations of Navy solar energy systems.

To obtain information, NCEL initiated on-site evaluations of solar systems installed at 10 Navy bases. The evaluations included solar domestic hot water systems installed on about 900 family housing units and other buildings including cafeterias, enlisted quarters, and swimming pools. Evaluations included inspections of a percentage of buildings at each base to determine overall system conditions, correctness of design, material compatability, common failure modes, and preventive maintenance procedures. This effort is being coordinated with similar work by the Army and Air Force to achieve a broader data base. The site evaluations are conducted by an experienced team from the Navy and the Los Alamos National Laboratory. The lessons learned from these site evaluations, particularly with regard to common failure modes, design errors, and other system quirks, are summarized below. It should be noted that not all systems suffer from the maladies listed below; indeed, many systems are functioning normally and the list is presented simply to identify common mistakes and failures and thereby improve future designs. Preventative maintenance will be more effective if the maintenance person knows what part of the system is likely to require his attention.

SUMMARY OF SITE EVALUATION RESULTS

With respect to the overall system:

1. The most common failure is the control system--including the sensors, controller, and pump (normally in that order of frequency).
2. The contractor should be required to provide an adequate system operations manual, set of drawings, and maintenance guide.
3. Occupants should be discouraged from tampering with the system but should be encouraged to report problems. Post signs, distribute brochures, etc., to encourage the proper response.
4. Systems that use glycol in the solar loop seem more susceptible to leaks and should be checked accordingly. The pH level of glycol systems should be checked annually and the results marked conspicuously on or near system. If the pH level is below 6.5, the glycol should be replaced. There are gauges that automatically indicate glycol charge. Provide taps to take samples.
5. Labels should be used to identify all heat transfer fluids other than water.
6. Although excessive instrumentation is not encouraged, if budget permits, thermometers should be installed on either the collector outlet or the storage tank or on both. On large systems this is an incidental cost and should be mandatory.
7. With respect to air collector systems all leaks invariably reduce performance and should be sealed. Ducts should be supported to prevent vibration, which opens joints. Wood should not be exposed to the airflow from collectors since it dries and cracks the wood. Backdraft dampers should be checked to ensure that they are not installed backwards. Rapid duct size transitions should be avoided. Tag pointers should be installed on damper shafts.
8. System freeze protection must be considered in cold regions. See Military Handbook 1003/13 (Naval Facilities Engineering Command, 1981) for different methods (pros and cons). Beware of circulating glycol below 32°F and freezing the water side of

the heat exchanger. Freeze protection sensors and controls must respond to 40°F, not 32°F, to compensate for nocturnal radiation effects.

9. Depending on the system, it is usually all right to turn off the backup energy source on sunny summer days.
10. In areas where electrical thunderstorms are commom, the collector array should be grounded to prevent damage to the controller from static discharge.

With respect to collectors and mounting hardware:

1. The results of the inspections to date show the collectors to be reasonably durable; however, inspectors should be trained to look for such things as cracking or discoloration of the cover plate, corrosion of the outer box, integrity of the seal, visible leaks, condensation under the cover, and outgassing on the cover.
2. If wood is used for mounting, it should be treated against deterioration.
3. Mounts must be tied down securely. Lag bolts should be checked to ensure that they are not just fastened to the sheathing material.
4. The proposed locations of collectors should be checked to ensure that they will not be in the shade during part of the year or in the future.
5. All fasteners used outdoors should be checked for corrosion.
6. The tendency is to over design collector mounts. Determine proper structural sizing; do not simply agree with what the contractor says.
7. The minimum clearance between the collectors and the roof and any side wall should be 1-1/2 inches unless the collectors form part of the roof.

With respect to the controller:

1. The controller should be matched with appropriate sensors, either 3,000 or 10,000 ohm.
2. If a control problem is indicated, the problem may be in the sensors and they should be inspected before any other action is taken (see the section on sensors below).
3. In general, the solar loop controls should be independent from the building Heating, Ventilating, and Air Conditioning controls.

4. The controller should be as simple as possible consistent with the job requirements.
5. The use of controllers with digital temperature readouts should be considered; although they cost more than those without digital readouts (about twice as much), they eliminate the need for separate thermometers.

With respect to sensors:

1. Sensors must be located properly as close to the collector absorber plate as possible. Some collectors have sensors attached directly to the absorber plate by screws or bolts and these work best. A location immediately outside the housing on the collector outlet pipe is acceptable. Tank sensors must be attached to the skin of the tank under the insulation or on the solar supply pipe immediately next to the tank. Get as close to the tank bottom as possible.
2. Sensors should be sealed with watertight silicone or a similar sealant. A hose clamp can be used to secure the sensor to the pipe before sealing. The sensor and pipe must be insulated so that the sensor reads pipe temperature and not ambient temperature.
3. The 10,000 ohm sensors appear to be more reliable than the 3,000 ohm sensors.
4. An ohmmeter can be used to quickly check sensors; a reading of zero or infinity indicates a bad sensor (disconnected from controller).
5. Installation of two sensor probes, with one serving as a potential backup, should be considered.
6. In freeze protection areas, two sensors are the required minimum. They should be wired in parallel, and then connected to the controller.
7. Sensor wires should be protected during installation. Sharp bends should be avoided. To prevent shorts, care should be taken when pulling wire through holes or over flashing and when stapling wire. Wire failure is the same as sensor failure.

With respect to pumps:

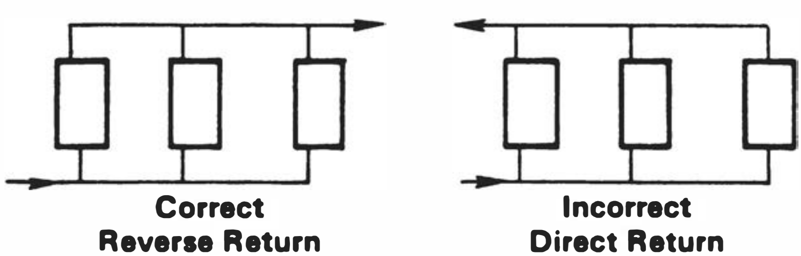
1. For small systems, correct flow rate generally is assured with currently available 1/35- to 1/12-hp pumps. For larger systems, collector loop and

storage loop flows should be checked to ensure that they are adequate and balanced.

2. In open loop systems, pumps with bronze or stainless steel impellers and body should be used. If a fluid other than water is used, the compatibility of the fluid to the pump should be checked.
3. Pump installations should be checked for correct flow direction.
4. Shutoff flanges are inexpensive and, when installed on either side of the pump, allow easy replacement and troubleshooting.

With respect to pipes and valves:

1. Valves should be tagged as normally "open" or "closed." Where there are many units, this also should be done in the operations manual kept in the maintenance shop.
2. Dielectric unions should be used if dissimilar metals are present to prevent galvanic corrosion.
3. If rubber tubing is used to connect collectors, silicone rubber is best. Spring clamps (constant tension) should be used rather than screw-type hose clamps. Collector outlet pipe with sealing rings or ridges (ferrules) works best with rubber. Straight pipe is difficult to seal.
4. Long pipe runs require loops or thermal expansion joints. All collector systems should be installed using a reverse-return (Z flow) piping layout: About 12 collectors in a row can be accommodated; when there are more than that, a flow balance should be done.



5. A manual collector drain valve should be provided at the low point.
6. Special care must be exercised when sealing roof penetrations in order to minimize future leaks.
7. Pipe runs and joints should be insulated to R-3 or R-4. Although rubber elastomer is most common, it does not appear to withstand ultraviolet radiation well. Metal claddings, Polyvinyl Chloride jackets, and "do-all" jackets work well outside. Uncladded elastomer is acceptable inside the building. If possible, insulation should be installed before assembly of joints so it can be slipped over the piping without slitting and glueing.
8. Domestic hot water systems need at least one pressure relief valve, air vent, and tempering valve. Air vents go at the high point and are perpendicular to the ground (not the collector).
9. High-temperature solder such as 95/5 tin/antimony should be used.
10. All pipes should be flushed after assembly but before final hookup.
11. It is relatively inexpensive to install thermal wells or test ports during construction and then to decide later if thermometers need to be installed. Appropriate locations for wells or ports are in the collector inlet and outlet, in storage tank, and in the hot water pipe leading to the load.
12. Spring loaded or swing check valves that do not require a pressure differential to seal should be used. Thermosiphon systems use thermally actuated check valves.
13. Soft seat valves should be used for diverting flow. Hard seat valves are okay in mixing applications.

With respect to storage tanks:

1. Externally located tanks should be well insulated and protected from moisture.
2. All tanks located in heated spaces (which is preferable) need at least R-11 insulation and pressure relief valves. For unheated spaces, insulation should be increased to R-20.
3. Dissimilar metal connections should be avoided. Use dielectric unions.
4. Convoluted pipe that runs in and out of the tank should be avoided.

5. In fiberglass tanks, stress concentrations should be avoided, especially at pipe attach points which should be at the top of the tank.
6. Tank supports should be thermally isolated from tank.
7. Buried tanks are not practical for use except in large systems because they deteriorate and are difficult to insulate.

CONCLUSIONS

On the basis of the information obtained during the on-site evaluations, a predesign checklist has been developed to highlight likely trouble spots and to provide guidance to those preparing a preventative maintenance program. Some of the major conclusions drawn are that:

1. Solar collectors appear to be in good condition with no major corrosion.
2. A lack of proper system drawings, operations manuals, valve identifications, etc., is prevalent.
3. Temperature sensor location and reliability is a source of problems.
4. A simple maintenance check (requiring only 10 to 20 minutes per system) would identify the majority of problems.

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VETERANS ADMINISTRATION EXPERIENCE WITH SOLAR ENERGY SYSTEMS

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INTRODUCTION

The Veterans Administration (VA) has an extensive solar program. It began in 1976 with a Wilmington, Delaware, project that included both solar heating and cooling. The latest system was put in operation only a few months ago. The VA now has 32 solar projects in operation at present. They serve a variety of building types and are located across the country.

The first VA solar system utilized flat plate collectors to provide building space heating and cooling. Later systems were directed towards providing domestic hot water only. The basic system design has evolved producing what the VA believes is an excellent, trouble-free, successfully operating system.

With regard to system operation and monitoring, the VA decided that it was not a research organization and, consequently, that it would not attempt to monitor systems extensively or to construct complicated research projects. The VA therefore provides instrumentation adequate to determine the proper operation of a system and simple controls to ensure proper maintenance in the field. This approach has worked successfully and, as a result, a majority of the VA systems have been operating properly for a number of years.

DESIGN

The VA's basic design philosophy and criteria have evolved over the past eight years and are now presented in a VA document entitled Design Guidelines for Solar Assisted Domestic Hot Water Heating Systems. It provides guidelines and identifies limitations regarding the scope and design of VA solar systems.

In general, the following parameters govern VA solar system design:

1. System--Domestic hot water preheat providing approximately 40 to 60 percent of total yearly domestic hot water load.
2. Collector--A single glazed, selective surface, flat plate, modular type collector.
3. Freeze Protection System--Ethylene glycol storage system with corrosion inhibitors incorporating two heat exchange surfaces between the glycol loop and the building hot water.
4. Storage Tanks--Sized approximately 1 to 1.5 gallons per square feet of collector panel. R-28 insulation on outdoor tanks and R-14 insulation on indoor tanks. Tanks located indoors in a mechanical room are preferred. Tank material is steel with internal and external corrosion protection.

EXPERIENCE AND DESIGN CONSIDERATIONS

The VA has found that the problems associated with its systems generally are due to inadequate detailing of the system. The basic design of the system is adequate. The problems occur with installation details of piping systems, mounting systems, insulation, shading, air elimination, and controls. Many of the problems are similar to those that occur in all heating systems; however, in solar systems they become more important because of the low grade of heat collected. Small mistakes can make dramatic reductions in energy collected. Solar systems are usually a supplemental system; consequently, if they are not operating properly, they can be valved out of the hot water system instead of repaired. With troublesome systems, this unfortunately is often the solution of choice. Some of the areas where proper detailing is essential are identified below.

General considerations include the following:

1. Collector Azimuth--Optimum azimuth is true South; a ± 20 degree variation is insignificant. Variation to the west is better than to the east.

2. Cover Plates--To prevent cover plate breakage, some collectors come with a protective adhesive paper. Remove this paper when temperatures are moderate otherwise the glue will be frozen or melted and impossible to remove.
3. Inner Condensation--Be sure the collectors have vent holes or weep holes to allow condensed moisture to escape and release the pressure. They must be placed so that they will not be blocked or collect rainwater.

With respect to collector mounting:

1. Choose structural mounting elements based on the design live and dead loads imposed (including contained fluid, piping, valves and accessories, seismic and wind loading up to 150 mph).
2. Mounting collectors 18 inches off the roof will allow room for access to the roof surface for repair or replacement.
3. Collectors should be mounted with adequate space for air circulation to disperse moisture buildup and growth of fungus under collectors.
4. Consider lightning protection for the collectors and the system.
5. Flashing should be galvanically compatible with collector construction. This includes supports and fasteners. Proper dielectric insulation must be used where incompatibility exists.
6. Room for expansion and pipe connections between modular collectors must be provided (6 inches minimum).
7. Wherever possible, absorbers should be allowed to "float" to compensate for expansion across the entire array.
8. All long runs of piping should have proper expansion connections before being attached to the array.
9. Provisions for avoiding high stagnation temperatures should be reviewed--considering especially whether liquid must be drained manually from collectors in summer.
10. Flow channeling (short circuiting) is undesirable if it occurs across the storage tank within one flow loop. In some systems, if the inlet and outlet to the building heating loop are installed on the same end of the storage tank, flow channeling between the inlet and outlet results in significant bypassing of

available stored energy. The inlet and outlet on any one flow loop should be installed at diagonal locations across the tank to improve flow distribution. A horizontal discharge pipe with many holes along its length will help greatly in assuring that flow channeling cannot occur within a given loop.

With respect to the piping system:

1. Care should be taken in the design and layout of the fluid transport system to prevent excessive pressures that result in flow restriction.
2. Piping should be flushed before collectors are connected. Fluxes, metal preparation chemicals, and loose bits of construction debris can harm some fluids or clog collectors. Where potable water is circulated through the collector array and calcification is possible, provision for flushing with a decalent should be considered. Fill connections should be placed upstream of check valves so that air is not trapped.
3. Provide adequate expansion joints and loops in piping and at equipment to permit free movement. Loops are preferable to joints. Properly designed guides and anchors are essential.
4. Galvanized piping has been a problem when the temperature of the fluid is higher than about 130°F.

   Galvanized piping should not be used in solar energy systems.
5. Piping should be arranged to provide for air purging; water velocities in collectors are low and usually not sufficient to carry air to elimination devices. Flow should always be in the direction of natural air movement.
6. To maintain even tube flow distribution, collector manifolding resistance should be low compared to tube resistance. Keep manifold resistance to about 10 percent of tube resistance.
7. Pipe insulation located outside should be protected from water and the ultraviolet rays of the sun. Pipe covers should be lapped and sealed to prevent leakage of water at joints.
8. Solar collectors have been damaged by thermal shock when they were initially filled. On a sunny day, an empty (dry) collector can reach very high temperatures. The absorber can be 450°F in a flat plate

collector. The initial start-up fluid entering the dry collectors, hundreds of degrees cooler than the absorbers, results in broken glazings, absorber warpage, and/or exploding of evacuated tubes. To avoid this disaster, the system should be filled during the early morning hours before the sun has heated the collectors.

With respect to the pumping system:

1. The pumps are similar to those utilized in a standard hot water heating system.
2. Mechanical seals should be suitable for 225°F or the maximum operating temperature, whichever is larger.

With respect to liquid storage systems:

1. Liquid storage tanks should be leak tested at 1.5 times the design pressure. Automatic relief valves should be incorporated to protect the tank against overpressurization.
2. Water inlets to storage tanks should be designed to minimize mixing in the tank. Dimension all tank connections on drawings.
3. Indicate and dimension the location of the tank temperature sensor.
4. Tanks should be provided with means for emptying the liquid. Those above grade or floor level should have a valve at the lowest point, and buried tanks should have provision for pump or siphon emptying.
5. Thermal storage system materials should be chemically compatible with one another to prevent corrosion and deterioration.
6. Heat losses from thermal storage containers, which are usually placed in basements or equipment rooms, must be accounted for in determining the thermal loading of these spaces.

With respect to system controls:

1. Controls should be kept as simple as possible. All set points and differential temperature settings should be easily adjustable.
2. For large buildings, the central computerized energy management and control system can and should be used to control the solar energy systems.

3. Collector loop controls must recognize solar input, collector temperature, and storage temperature. Controls also must allow the collector loop and the utilization loop to operate independently.
4. Controls must be "fail safe."
5. Collector sensors should be mounted on the collector surface, not in the piping.
6. If a collector array is partially shaded, the temperature sensor that activates the pump should be placed so that excessive on/off cycling is not induced. This may occur if the sensor is in a minority of the collector array that is hot while the rest remains shaded. Some cycling is inevitable during start-up or shut-down. It may be minimized by maintaining a large temperature difference in the control and securely fastening the sensor on the collector surface.
7. Normal operation of the differential controller and over-temperature controls can be subject to outside interference.
8. Monitoring systems and control systems should not be integrated. Controls should be kept separate.
9. A separate control panel should be provided for the solar system.

GENERAL SERVICES ADMINISTRATION'S EXPERIENCES WITH SOLAR HEATING AND COOLING SYSTEMS

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For several years, the General Services Administration (GSA) has been designing, installing, and putting into operation solar heating and cooling systems in federal buildings. One example is the solar system in Federal Building (FB) 103 in St. Louis, Missouri. It was designed in 1978 and put into operation in 1980 at an approximate cost of $1 million. The system is a General Electric evacuated-tube solar collector with an area of 20,000 square feet. The system was expected to provide 500 tons of refrigeration and reheat for computer rooms. However, numerous problems including high maintenance, breaking of evacuated tubes, and malfunctioning or improperly designed controls have been encountered since operation began. The system does not meet expectations; it has provided a maximum of 125 tons of cooling compared to the expected 500 tons. Another problem is that at night and on cloudy days the absorber temperature drops and causes the system to require steam from other sources. Because of such problems, this solar system is being redesigned to provide domestic hot water for a cafeteria instead of heat for absorption cooling.

Another example is the system in the federal building at Carbondale, Illinois. This system features an Owens-Illinois "Sun Pack" solar collector with an area of 5,200 square feet and a storage capacity of 25,000 gallons. This system was designed to provide both heating and cooling. Like the system in FB 103, this system has experienced numerous problems that have required excessive maintenance. The system requires operating technicians with higher than ordinary skills because of its sophisticated controls. In addition, many collector tubes have been broken. The Carbondale

FB is using approximately 215,000 Btu of energy per square foot per year, whereas it was designed for 55,000 Btu per square foot. Most of this energy inefficiency is attributed to the solar system. The system does not provide enough hot water for the absorber; therefore, the standby electric boiler has to be operated to generate high-temperature hot water for the absorption machine. GSA's Regional Energy Conservation Branch is attempting to retrofit the system.

The solar energy system on the Federal Building in Saginaw, Michigan, has experienced problems and inefficiencies similar to those of the Carbondale FB system. The Saginaw system, however, has not experienced excessive solar collector tube breakage.

The GSA has installed solar systems on many other federal buildings and the performance of all has been marginal. It should be noted that the problems encountered by the GSA are similar to those reported by other Federal agencies and the private sector. Nevertheless, during the past decade many lessons have been learned that affect future applications. This includes the following:

1. Present solar cooling systems are not cost-effective, require high maintenance, and are unreliable.
2. Simple systems such as domestic hot water systems are functional and, if designed and operated properly, are cost-effective in certain locations.
3. Solar systems require a specialized operating staff and should be installed only in areas where qualified technicians are available.
4. Present technology requires high levels of expertise in design and operation and also the exercise of human judgment.
5. Active solar systems should be researched extensively before more applications are made. In conclusion, present active solar systems are not cost-effective for cooling and space heating. Therefore, future planning should concentrate on state-of-the-art passive systems and hybrid systems to conserve energy. For further information, contact Vijay Gupta, Technical Directives Branch, Design Management Division, Office of Design and Construction, Public Buildings Service, on FTS 566-0628.

THE DEPARTMENT OF ENERGY'S SOLAR IN FEDERAL BUILDINGS PROGRAM

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The Solar in Federal Buildings Program (SFBP) is a multi-year program that was legislated in 1979 to stimulate the growth and improve the efficiency of the solar industry by providing funds to federal agencies for the design, acquisition, construction, and installation of commercially applicable active solar hot water, heating, cooling, and process heat systems and passive systems in new and existing federal buildings. The program was intended to place the federal government, the largest energy consumer in the United States, in the forefront in implementing energy conservation measures and in promoting use of solar and other renewable energy resources. To date, the program has progressed through planning and organization, proposal submission and evaluation, site selection, design, and design review for all 731 projects included in the program. In addition, construction and acceptance testing are over 75 percent complete, and the monitoring and reporting phase is now under way. The Department of Energy (DOE) has overall management control of the program and has contracted with Energy Technology Engineering Center (ETEC) to provide the technical management.

The budget for the project is approximately $30 million. The amount allocated for each site varies with the system complexity. There are many small systems to allow a large number of solar projects to be funded. The following is a list of the number of solar energy systems installed, categorized by system type:

Hot Water, Active	659
Heating, Active	11
Cooling, Active	1
Heating and Hot Water, Active	25
Heating, Cooling and Hot Water, Active	2
Process Heat, Active	10
Passive or Hybrid	18
Heating and Cooling, Active	5
	731

With most of the design and construction work completed, the program is now entering the multiyear monitoring and reporting process. The objective of the performance monitoring and analysis phase is to provide the facts on which to base performance predictions, confidence, and warranties for a mature solar thermal industry. This monitoring and analysis program is designed to evaluate accurately the field performance of representative designs of active solar domestic hot water, heating, cooling, and industrial process heat systems. Information on thermal performance, reliability and maintenance, and fuel cost savings will provide a realistic base for the solar energy technical community to improve its products, upgrade its system design methodologies, and supply solar thermal systems that perform as predicted.

At least 12 active solar sites will be instrumented for complete and accurate data recording. The data from these sites will be thoroughly reviewed and analyzed and made available to those engaged in research and development and design analysis methodologies. Ten other sites will be instrumented to a limited extent and the data from all the sites will be studied to detect major performance failures. In addition, several passive/hybrid projects will be instrumented and monitored.

Solar technical media, conference papers, and other publication vehicles will be used to disseminate intermediate results. Reporting during this monitoring phase will inform the solar community of ongoing activities in the SFBP and will communicate significant progress in a timely manner.

At the conclusion of the monitoring and performance phase, detailed reports will be issued to fully document the results obtained in the program. In addition, reports from this program will supplement several documents now in common use in the solar community, such as design guidelines, to make them more useful to designers and installers.

U.S. POSTAL SERVICE'S PASSIVE SOLAR BUILDING DESIGNS

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In early 1981 the Postal Service initiated a program to design and construct passive solar buildings. The program emphasized passive solar designs in small buildings ranging in size from 5,000 to 25,000 square feet.

Qualification as a passive solar project requires a significant solar energy contribution to the building systems. At least two of the following three criterion must be met:

1. Passive solar gains will provide or reduce the building heating energy requirements by a minimum of 35 percent.
2. Passive solar cooling will provide or reduce building cooling energy requirements by a minimum of 15 percent.
3. Natural lighting will provide or reduce building lighting energy requirements by a minimum of 10 percent.

Hybrid systems combining passive solar elements with active elements such as fans and pumps to distribute the energy are permitted to increase energy transfer or to control the passive solar elements. For cost control, the differential cost for the passive designed buildings, compared to standard energy efficient designs, is limited to $5 per square foot. Currently, the Postal Service has completed 12 passive solar buildings, 12 more buildings are under construction, and another 10 buildings are in design.

Passive solar design features are included in new major facilities when an economic analysis indicates that the features are life-cycle cost-effective. The construction of the Santa Ana, California, General Mail Facility, a 340,000 square foot major mail processing facility, is nearly complete with occupancy scheduled for June 1984. The facility has office daylighting through an atrium and a 200,000 square foot single story workroom features skylights for daylighting. The skylights serve a dual purpose by providing both daylighting and a means for smoke and heat ventilation for fire control. The workroom has a high intensity discharge lighting system with high pressure sodium lamps controlled by photocells and a dimmer system to provide automatic control of the illumination level. Daylighting and other energy efficiency elements of the Santa Ana design are calculated to provide a savings of 55 percent compared to the design of similar buildings in 1975.

SOLAR SYSTEMS
CONSTRUCTED BY THE INDIAN HEALTH SERVICE

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The Indian Health Service (IHS) has funded the installation of solar systems on hospitals located in Ada, Oklahoma; Whiteriver, Arizona; and Acoma-Laguna and Santa Fe, New Mexico. The hospitals contain from 40 to 70 beds. The collector areas vary from 10,000 to 30,000 square feet. All the systems feature fixed, flat bed collectors except the one at Whiteriver, which has sun tracking parabolic troughs.

Each is an active system with the collectors installed on the roof or a hillside nearby (Whiteriver). Each system is comprised of three stages. Stage one circulates glycol-water through the collectors and a heat exchanger. Stage two picks up heat at the exchanger and delivers it to the storage tanks. Stage three takes the hot water from the tanks and delivers it to the terminal units.

These systems are not very efficient because of heat loss in the lines and tank, the large amounts of water that must be pumped, and the fact that the stored water does not reach a usable temperature until midday. A higher efficiency could be attained by repiping, using variable volume pumps, and, as it becomes available, passing the hottest water through one or more of the terminal units. The terminal units are for building heat, domestic water, and absorption air conditioning.

CORPS OF ENGINEERS EXPERIENCE WITH SOLAR ENERGY SYSTEMS

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BACKGROUND

In the mid-1970s Congress began including in the yearly military construction authorization and appropriation acts a requirement that studies be conducted to determine the potential for savings from use of solar energy in military buildings. The acts also provided extra funds for installation of solar heating and cooling systems. The Army did not then have a guide specification or design manual for solar systems but it proceeded anyway and built approximately 50 percent of all the systems ever installed at Army installations before such documents were published.

In 1978 Congress firmed up the solar requirement. It directed that solar feasibility studies be conducted as part of the design of all military buildings and that solar systems be installed whenever they were found to be "cost-effective." Congress indicated that for a system to be considered cost-effective, "investment cost differential must be recovered over the expected building life." The Department of Defense (DOD) developed a special procedure for making life-cycle cost (LCC) analyses for solar projects that reflected the Congressional intent. The procedure was special in that it ignored operating and maintenance costs and it provided for escalation of energy savings. With that action, the DOD solar program was formally initiated.

In 1980 Congress changed the rules for determining the cost-effectiveness of a project. It directed that DOD begin using the new LCC analysis procedure that the National Bureau of Standards (NBS) had recently developed for the Department of Energy (National Bureau of

Standards Handbook 135). At this point, the Army solar energy program virtually ended since active solar systems were almost never found to be cost-effective by the NBS LCC procedure. The Army is still required to study solar applications for all buildings but finds few projects each year to be cost-effective.

With active systems found not to be cost-effective, the Army currently is pursuing passive solar energy applications and its major thrust is in the family housing program. During the past 3 years, passive solar systems were found to be cost-effective for 517 family housing units, all of which have been built or are under construction (232 at Fort Drum, 26 at the Picatinny Arsenal, 115 at Fort Lewis, and 144 at Fort Irwin). This year's passive solar systems were found to be cost-effective for 652 family housing units and these are currently being designed (208 at the Aberdeen Proving Ground, 244 at Fort Stewart, and 200 at Fort Polk).

THE CURRENT SITUATION

In hind sight, it is evident that 1980 was a pivotal year in the use of active solar systems in the Army. First, as mentioned above, after the NBS procedure began to be used to make LCC analyses, few systems were found to be cost-effective. Second, users of active solar systems began experiencing and reporting numerous problems. As a result, active solar programs in general, and the Army program in particular, entered a new phase, a technology refinement phase.

The Army, through its Construction Engineering Research Laboratory (CERL) and its Facility Engineers Support Agency (FESA), undertook a research effort to correct Army solar problems and to find ways to make active solar systems cost-effective. Congress repeatedly prodded the Army and other military departments to find ways of improving and applying solar technology.

Among the research projects undertaken by the Army were the following:

1. A survey of active solar systems (by the Los Alamos National Laboratory).

2. Development of a solar feasibility (computer) program (now called SOLFEAS) to be used in the early stages of design to determine if a particular solar application is cost-effective (by CERL).
3. Analysis of the results of the survey of systems to identify lessons learned and common deficiencies and to establish a data base for follow-on work.
4. On the basis of experiences and lessons learned, development of a standard design for a reliable solar system for future use, a list of appropriate materials to ensure reasonable lifetimes for future systems, acceptance testing procedures (including appropriate instrumentation packages), and specific operating and maintenance procedures and schedules.

NEXT YEAR (OR AS SOON AS POSSIBLE)

Using the results of the research projects mentioned above, the Army will revise its solar design (technical) manual, solar guide specifications, and instructional courses for designers, maintainers and inspectors of solar systems. When the revised manual and specifications are available the Army expects to be able to build cost-effective active solar systems through use of a proven design employing reliable components and materials that meet or exceed design expectations. Thus, the Army will no longer permit unsuccessful, unproven, and untested systems or materials to be used. It anticipates some complaints and protests from bidders and manufacturers whose products or designs no longer meet Army requirements but expects to successfully defend its requirements through the use of competitive bidding documents and specifications that can be met by three or more suppliers.