DOE/NASA TECHNICAL MEMORANDUM

DOE/NASA TM-78172

HARDWARE PROBLEMS ENCOUNTERED IN SOLAR HEATING AND COOLING SYSTEMS

By Mitchell Cash
Solar Heating and Cooling Project Office
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

May 1978

For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
DOE/NASA TM-78172		

4. TITLE AND SUBTITLE	5. REPORT DATE
Hardware Problems Encountered in Solar Heating and Cooling Systems	May 1978
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Mitchell Cash	8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812	10. WORK UNIT NO.
	11. CONTRACT OR GRANT NO.
	13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Solar Heating and Cooling Project Office

16. ABSTRACT

Marshall Space Flight Center personnel have worked for several years with the development and demonstration of solar heating and cooling systems in support of the Department of Energy. In this work, they have encountered numerous problems in the design, production, installation, and operation of the solar energy systems. Many of these problems have been seen in more than one system. This report describes the hardware problems, which range from simple to obscure and complex, and their resolution. It is intended to provide personnel in the solar energy field with information that will help prevent the installation of solar heating and cooling systems that will not operate satisfactorily or that will not last for the design lifetime.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
	Unclassified-Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	39	NTIS

MSFC - Form 3292 (Rev December 1972)

For sale by National Technical Information Service, Springfield, Virginia 22151

ACKNOWLEDGMENTS

The author wishes to express his appreciation to all those at the Marshall Space Flight Center who contributed to the compilation of this report. Because of their number, it is not practical to list them. Particular thanks go to Albert C. Krupnick and Erwin H. Simon for their review and suggestions concerning the description of the problems and their resolution.

TABLE OF CONTENTS

	Page
SUMMARY	1
I. INTRODUCTION	1
II. MARSHALL SPACE FLIGHT CENTER PROGRAMS	2
A. Development	2
B. Commercial Demonstration	3
III. INSTRUMENTATION	3
IV. HARDWARE PROBLEMS	4
V. SYSTEM PERFORMANCE	5
VI. CONCLUSIONS	6

LIST OF TABLES

Table	Title	Page
1.	General Collector Problems	7
2.	Liquid Collector Problems	13
3.	Air Collector Problems	17
4.	Storage Problems	18
5.	System Problems	22

TECHNICAL MEMORANDUM

HARDWARE PROBLEMS ENCOUNTERED IN SOLAR HEATING AND COOLING SYSTEMS

SUMMARY

This report describes the Marshall Space Flight Center's experiences with hardware problems in solar heating and cooling systems, subsystems and components, and their resolution. It identifies the mistakes made so that they need not be repeated by others in the future. It also describes the importance of measuring the performance of the systems.

I. INTRODUCTION

The 1973/74 energy crunch caused by the foreign oil embargo and subsequent concern over the fossil fuel available in this country generated considerable interest in the use of solar energy. A number of books and papers have been published on the design of solar heating and cooling systems, but they are primarily theoretical in nature. There is a dearth of material on translating a design into practical hardware. Consequently, many of the builders and installers are learning the hard way — through their own mistakes, frequently the same as others have made.

The Department of Energy (DOE) is responsible, among other functions, for the development and demonstration of the feasibility of heating and cooling of buildings and heating hot water using solar energy. Through an interagency agreement, the Marshall Space Flight Center (MSFC) of the National Aeronautics and Space Administration (NASA) supports DOE in development for the Demonstration Program and in management of some of the Commercial Demonstration Projects. In addition, MSFC has conducted limited in-house development on selected components and materials, and has operated a solar heated and cooled "house" on the Center for several years.

The MSFC personnel have encountered numerous hardware problems in solar energy systems. Some of the problems were recognized early at design reviews and corrected before they became actual hardware problems. Some were encountered during development and production of the solar hardware, while others were encountered during the installation and operation of the systems, and during inspection of other projects. With experience and hindsight, many of the problems seem to be elementary. However, some are peculiar to solar equipment and are not readily recognized by the newcomer, while others are complicated or subtle and may take months or years to become visible.

The intent of this report is to help prevent the installation of unsatisfactory solar heating and cooling systems. It provides a list of "don'ts" for the designer, builder, and installer of solar heating and cooling systems. Those now in the business may find some of the more subtle problems are applicable to their hardware. Basic problems have been included for the newcomer and "do-it-yourselfer." This report will also provide purchasers of solar equipment with a basis for formulating questions that may help identify unsatisfactory hardware. In addition, some information on system performance has been included as a guide to satisfactory operation of the system.

Manufacturers and hardware are not identified by name, since the problems listed have been corrected. Furthermore, the same problems may exist uncorrected in hardware made by others.

II. MARSHALL SPACE FLIGHT CENTER PROGRAMS

A. Development

In the development work in support of the DOE Demonstration Program, MSFC has awarded 35 contracts to industry through competitive procurements. These contracts were for the procurement of existing marketable solar heating subsystems, the development of existing solar heating and cooling systems and subsystems, the integration of the procured subsystems into solar heating systems, and the development of complete, integrated, optimized solar heating and combined heating and cooling systems. The systems include single family, multifamily, and small and large commercial sizes. They are hot water only, space heating, and space heating and cooling systems, with most of the latter two having hot water subsystems. One of the contractors also developed the instrumentation system described in Section III. The development work varied considerably, and included documentation (drawings, manuals, etc.), testing, certification, hardware improvements, and new subsystems.

Each of the development contracts went through a series of design and acceptance reviews in an effort to eliminate problems before the system was manufactured or delivered. The completed system was installed in a building and an operational test was conducted for 6 months (1 year for heating and cooling systems). The systems were instrumented and data were collected during this period to verify the performance and determine operational problems. If the system performs satisfactorily it is considered to be ready for inclusion in the DOE Demonstration Program.

B. Commercial Demonstration

DOE and its predecessor, the Energy Research and Development Administration (ERDA), have released three Program Opportunity Notices (PON) for commercial demonstrations of solar heating and combined heating and cooling systems. MSFC has participated in the evaluation of the proposals and has been given the responsibility of contracting and managing a number of these demonstrations. Under these contracts, each site owner or his agent designed, procured, and installed the solar energy system. Then, in accordance with an agreement with the Government, the system is operated for up to 5 years as a part of the Demonstration Program. Each of these systems went through a series of design reviews and an acceptance review similar to the development program to eliminate problems prior to installation. A number of the systems were also instrumented to determine the performance during the operational period.

III. INSTRUMENTATION

The systems installed for the MSFC program have an instrumentation system provided by the Government. (It is planned to install this same instrumentation system in more than 200 buildings in demonstration programs conducted by Government agencies for the DOE.) The system consists of a number of sensors (temperature, flow, power, insolation, wind velocity and direction, etc.) necessary to determine the performance of that particular system. These sensors provide an output to the Site Data Acquisition Subsystem (SDAS), which scans all the sensors at 5 minute intervals (some can be scanned more rapidly if necessary) and records the data on tape. The central computer located at Huntsville, Alabama, then calls the SDAS (usually daily) through a telephone line and reads the data on the tape. The tape is then erased and is ready to continue recording data. The central computer calculates and prints the performance of the system in a predetermined format. On completion of the operational test or demonstration, a performance report will be prepared and will be available to the public through the DOE Technical Information Center at Oak Ridge, Tennessee.

IV. HARDWARE PROBLEMS

The hardware problems encountered are defined in Tables 1 through 5. These tables give the problems encountered and their resolutions, however, the resolution listed for a particular problem may not be the only one possible (or necessarily the best) as situations can vary with hardware, locality, etc. Table 1 lists general problems that could be found in most types of collectors; Tables 2 and 3 are restricted to specific problems of liquid and air collectors, respectively; Table 4 describes problems related to storage subsystems; and Table 5 describes system problems — some problems related to more than one subsystem.

Many of the problems became obvious during design, production, installation, and checkout. Others did not become apparent until the system had been in operation for some time. This is particularly true of problems associated with deterioration under long-term usage and stagnation temperatures [the temperature which the collector can reach under maximum insolation and no flow of the heat transfer medium — typically, 150-200°C (300-400°F) in flat plate collectors and much higher in concentrating collectors]. Many of the problems were caused by poor workmanship, resulting from a lack of recognition of the more stringent requirements of solar installations as compared to normal plumbing and heating practices.

The problems described in this report should not be used as a guide to selection of a system. For example, the freezing problem associated with water systems does not indicate that an oil or air system is necessarily preferable, nor does the relatively problem-free performance of air collectors indicate that they are necessarily preferable to liquid collectors. Each type system has its advantages and disadvantages, and selection should be based on purpose, location, cost, and desired results. Eliminating problems will then reduce costs and improve results.

A major characteristic of solar heating and cooling systems — the high initial cost — is not listed on the tables. Collector costs are high. Improved designs, improved fabrication techniques, and volume production will help bring down the original equipment costs. Installation costs are also high. Improved designs, greater familiarity with installation techniques, and increased competition will help bring these down. In addition, rising energy costs will make solar heating and cooling systems cheaper relative to the cost of conventional systems. Lack of long-term test data under operating conditions is also a concern.

V. SYSTEM PERFORMANCE

There is a tremendous amount of solar energy falling on the Earth, but it is spread over a large area. Consequently, the amount falling on a unit area is relatively small. This is further reduced by cloud cover and air pollution. The amount available for collection is also affected by the latitude of the site, the orientation and tilt of the collector, the time of day, and other factors. Therefore, it is important that what is available be efficiently collected and conserved, which means optimum system operation and adequate insulation.

Without instrumentation, many of the problems noted herein would not be known, as the backup auxiliary system will automatically provide the heating or cooling. The wrong location of a control sensor will not keep the system from operating — it will just function at less than maximum performance, and the owner will not be achieving the desired savings. An example of a subtle performance/control interface problem is a liquid solar energy collection system with a heat exchanger in the storage tank. If a cylindrical tank is used for storage, the required heat transfer area of the coils may extend from the bottom to the middle of the tank. The water in these tanks tends to stratify near the middle of the tank, with temperatures at the top and middle of the tank varying about a degree, and the bottom of the tank being as much as 20°C (36°F) or more lower. If a 5°C (9°F) differential temperature is used between the bottom of the tank and the collector to start the collector pump, the fluid coming into the heat exchanger above the stratification may be cooler than the surrounding water, with a resultant decrease in system efficiency. Under certain conditions, heat may even be rejected from the tank through the collectors to the atmosphere. Increasing the differential may eliminate this problem, but also may result in collecting less solar heat. Moving the sensor higher may put it above the stratification level, which would also require higher collector temperatures before startup and possibly less total collected heat. The problem is further complicated when the building load pump starts, if this destroys the stratification. The collector pump control sensor in the storage tank will then record a fairly rapid temperature increase or decrease, depending on its location with relation to the stratification. If the sensor is at the bottom of the tank, it will have a temperature increase that could shut off the collector pump due to a reduction in the collector differential temperature.

Therefore, it is very important that a means be provided to monitor the system. This can vary from a minimum of two thermometers in a simple system to complex recording devices in a large and expensive system. The guide for this should be the same as for the entire system — the payback period. The ultimate objective in solar heating and cooling systems is that the savings in cost and fossil fuel must exceed the cost and fuel consumption of an equivalent conventional system over the life of the solar energy system.

VI. CONCLUSIONS

The mistakes found to date in the design, production, installation, and operation of solar heating and cooling systems show there is much to be learned. As knowledge of these problems becomes more widespread, their incidence will decrease. A means to know that the system is performing properly is important to ensure the maximum benefits, as improper operation of the system is one of the most difficult problems to detect.

TABLE 1. GENERAL COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Improper Manufacture	Galvanized sheet metal was sheared and bent to form collector housing, but the sheared edges were not treated to prevent corrosion.	Field touchup of untreated edges was required to prevent deterioration.
Corrosion	Hardware supplied by manufacturer included some noncorrosion-resistant parts such as black steel screws.	Use only corrosion-resistant hardware.
Collector Mounting	Mounting hardware was not shipped with collectors. Vendor drawings noted mounting details to be furnished later. Vendor claimed price quoted did not include mounting hardware.	Ensure understanding of what is included in quoted price. In this case, vendor reluctantly agreed to ship the mounting hardware.
Mounting Tools	Mounting hardware furnished with collectors required a special tool to attach blind fasteners.	Ensure understanding of tools required to install hardware.
Collector Sealing	Pressure plate seal vibrated loose during shipment. Poor fit was found on collector case in areas of spot welds.	Proper caulking and better welding techniques required.
Shipping Damage	Collectors were damaged in shipment because vendor did not provide protective packaging and packed too many in truck.	Proper packing and shipping procedures are required.

TABLE 1. GENERAL COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Buckling of Absorber Plate	With high insolation, absorber plate buckled enough to touch cover and damage absorber coating.	Redesigned for adequate expansion and "floating" of absorber plate.
Movement of Glazing	Rough handling of collector caused glazing to slip out of place under sealing gasket.	Proper design to minimize clearance and careful handling.
Material	Foam used for structural purposes in a collector deteriorated under stagnation temperatures.	Changed to a foam material that was stable at high temperatures.
Insulation Deterioration	Swelling of foam insulation under stagnation temperatures deformed collectors causing contact between aluminum and copper parts with resultant galvanic action.	Added expansion slots in insulation (temporary fix). Change to stable insulation
Shipping Damage	Glazing was shipped separately but not opened on receipt. When opened, they were found damaged, but it was too late to file a claim against the shipper.	Inspect on arrival.
Transmissivity	A collector had glazing that was not high in transmissivity, resulting in poor performance.	Change to a glass cover with high transmissivity.
Shipping Damage	Forklift jabbed into packaged collectors causing damage.	Proper handling.

TABLE 1. GENERAL COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Maintainability	Inadequate accessibility to individual collectors and piping on large array.	Redesign array.
Wind Loading	Stress analysis on collector roof support showed it to be good only for moderate wind load.	Redesign supports for maximum wind load.
Glass Breakage	Glass breakage after installation was attributed to lack of edge treatment after cutting. This results in high thermal stress concentration at the rough points that propogate to cracking.	Smooth edges of glass prior to installation (grinding, flame, etc.).
Condensation Between Double Glazing	Condensation deposited residue and resulted in some loss of transmissivity.	Assemble collectors when there is little moisture present.
Shipping Damage	Shipping damage destroyed galvanized coating on collector pan resulting in excessive corrosion in the salt air of that site.	Replaced damaged and corroded collectors.
Expansion of Insulation	Closed cell foam insulation expanded under high temperature causing buckling of collector panel and separation of glazing.	Allow for expansion of insulation.

TABLE 1. GENERAL COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Atmospheric Particles Deposited on Glazing	Particles such as dirt in the air deposit on the glazing. The ordinary deposits do not reduce transmissivity greatly and wash off in the rain; however, some oily particles generated by industrial processes may not wash off with rain.	Determine if there are contaminants in the air at the installation site that will not wash off with rain. If necessary, provide access for periodic cleaning.
Rain Leakage Due Improper Assembly	Burrs and shavings from drilling were left on pieces during assembly and prevented proper mating of two surfaces at the glazing seal with consequent leakage.	Ensure that burrs at drilled holes and foreign matter are not left where they will prevent proper mating of collector parts.
Shipping Damage	Absorber plates were shipped stacked in horizontal positions and held apart by notches in the packing frame. During transportation, the packing frame sheared at notches, dropping all plates in stack to bottom of crate.	Ship on edge or use blocking between plates (provided blocking does not damage absorber surfaces).
Improper Flow Distribution	Inlet and outlet on the same end of collector resulted in the flow going directly from the inlet to outlet without proper distribution throughout the collector.	Place inlet and outlet diagonally opposite each other for maximum flow distribution (some collectors that appear to have adjacent inlet and outlets may have correct internal distribution with internal piping leads to the same end).

TABLE 1. GENERAL COLLECTOR PROBLEMS		
PROBLEM	**DESCRIPTION**	**RESOLUTION**
Heat Loss	Inadequate insulation on back and edges of absorber plate caused large heat losses.	Use adequate insulation.
Glass Breakage	Plain glass has a tendency to break under the stresses induced by high temperatures.	Use tempered glass or plastic glazing to prevent breakage.
Glass Breakage	Glazing was restricted from expanding as it heated and then shattered.	Allow adequate means for thermal expansion at stagnation temperatures.
Paint Peeled	Absorber paint peeled and cracked at high temperatures due to improper application.	Follow manufacturers recommended application procedures for high temperature usage (degreasing, wash primer, painting, etc.).
Paint Deterioration	Absorber paint deteriorated (discoloration, peeling, cracking, etc.) because it was not suitable for stagnation temperatures.	Use paints that have been tested for long terms at the expected stagnation temperatures.
Structural Failure During Handling	"Racking" during handling caused welded corners of the aluminum frame to break.	Use adequate strength welding or use mechanical fastenings at corners.
Wood Deterioration	MSFC has not tested the use of wood in collectors. However, it has been reported that long-term exposure of wood to the high collector temperatures results in a pyroforic condition that breaks down the wooden cell structure and lowers its ignition point.	It is not considered desirable to use wood in the collector where high temperatures are reached.

TABLE 1. GENERAL COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Glazing Deterioration	Some types of polymers deteriorate when exposed to moderate or high temperatures, and others soften, expand, and sag.	Investigate properties of glazing to ensure that it is satisfactory for use at the temperatures expected for the desired life of the glazing.
Material Deterioration	Some materials deteriorate under ultraviolet radiation contained in the solar spectrum.	Select materials that do not deteriorate when exposed to sunlight and are resistant to ultraviolet radiation.
Mechanical Abrasion of Flexible Glazings	Wire supports were placed under a thin film polymer glazing for support, and the glazing was glued to the wire. Abrasion in the glazing caused by contact with the wire destroyed the glazing.	On flexible outer glazing that can flutter in the wind, eliminate cross supports that would wear or stress the glazing or use supports with sufficient surface to minimize stresses.
Outgassing	Certain materials (insulation, sealants, etc.) with volatile components emit gasses at higher temperatures that deposit on the inside of glazing and reduce solar transmission.	Use materials that do not outgas at maximum expected temperatures (i.e., insulation without binder) or, prior to assembly, are baked at temperatures exceeding stagnation temperature.
Heat Loss	Absorber plate was fastened by metal directly to the collector frame.	Thermally isolated absorber plate from frame.

TABLE 2. LIQUID COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Freezing of Drain Down System	Rubber hose connection from collector to manifold had low spots that did not drain completely and froze.	Proper installation so all water can drain.
Excessive Flow Rates	Excessive flow rates resulted in loss of efficiency.	Changed to proper flow rates.
Reflector Installation	At low Sun angles in the winter, reflectors did not catch direct sunlight.	Reevaluated installation angle of reflectors and significance of contribution.
Redundant Piping	Analysis of drawings revealed redundant water circuits.	Eliminated redundant circuits.
Freezing	Glycol water mixture was not sufficient to prevent freezing due to water being added through an automatic makeup valve.	Eliminate automatic water makeup.
Pressure Relief Valve Failure	Moisture in valve froze preventing operation.	Relocated pressure relief to nonfreezing area.
Freezing	Drain down collectors retained enough water to freeze.	Air lines added to prevent "water trap" in drain down lines.
Hose Deterioration	Rubber hose connectors deteriorated due to ultraviolet radiation.	Change to stable hose, use metal connectors, or place protective cover over hoses.

TABLE 2. LIQUID COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Drain Down Failure with Possibility of Freezing.	Drain down shutoff valves between collector and pressurized tank did not seal permitting water to be forced back into collectors. Piping not properly sloped for complete draining. Both could result in freezing.	Ensure proper sealing of valves and proper installation of piping.
Freezing	Workmen working on collector stood on pipes and bent them so water did not drain. Pipe subsequently froze.	Observe careful installation procedures.
Internal Moisture	Many collectors had enough moisture in them to cause condensation on cold nights.	Remove moisture by baking prior to assembly or open cover and dry in field.
Moisture Condensation	Simple dessicant system did not eliminate moisture condensation.	Dessicant container was redesigned to prevent saturation of dessicant by ambient air.
Freezing of Collector	Moisture in the collector vent valve froze, preventing opening and drain down of collector.	Used an improved vent valve.
Drain Hole Location	Collector was designed for vertical mounting. When installed horizontally, the drain holes were in wrong location.	Changed drain holes to bottom of horizontal collector.
Leakage from Rain	Water standing in collector due to leaks at glazing seal.	Adequate sealing of glazing or drain holes at lowest points.

TABLE 2. LIQUID COLLECTOR PROBLEMS		
PROBLEM	DESCRIPTION	RESOLUTION
Corrosion Due to Galvanic Action	Certain dissimilar metals create an electrolytic action that can rapidly transfer metal from the more "base" to the more "noble" metal when in direct contact or when there is water in contact with both surfaces.	Avoid using dissimilar metals or use a corrosion inhibitor if water is transport fluid. If dissimilar metals must be used, provide isolation between them to eliminate galvanic action through direct contact.
Internal Leakage	Hose with clamp connection was within the collector behind the absorber plate. Leaks were difficult to find and repair.	Use mechanical or soldered connections inside the collector.
Flexible Connections from Collector to Manifold	Hose flexible connectors were secured with screw type clamps. "Give" in the hose with time resulted in leaks.	Use spring loaded type clamps that maintain constant compression on hose and use hose that does not develop a permanent set with time.
Flexible Connections from Collector to Manifold	Connections were bent to a radius less than design. This caused a kink, which (though it did not leak) could result in an early failure.	Install flexible connectors without excessive stress and with adequate radius.
Collector Damage	A collector with a tube outlet designed for a compression fitting did not have a means for holding the tube while a torque was applied. Thus, the tube could be twisted off at the tube/absorber attachment.	Provide a configuration that could hold the tube while a torque was applied during assembly.

TABLE 2. LIQUID COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Venting	Collector had diagonally opposite inlet and outlet tubes, which provided proper filling and venting when installed with bottom edge horizontal or vertical. When installed on a nearly flat roof with bottom edge at an angle from horizontal, the outlet was not the highest point of the collector.	Added an alternate configuration to the design, with the inlet and outlet connections diagonally opposite, but in the other two corners. This provided an outlet at the high point of the collector when installed.

TABLE 3. AIR COLLECTOR PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Leakage	Loss as high as 20 to 35 percent of the air volume into collectors has been found. While some leakage can be found in most hot air heating ducts, it does not reduce system efficiency if the loss is to the heated space. Losses through a collector are to the outside and reduce the solar heating efficiency; it also can reduce the regular heating system efficiency when the solar is not running, as leaks are then to the outside.	Adequate sealing of collectors and ducts outside the heated space.

TABLE 4. STORAGE PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Stratification in Liquid Tank not Accomplished	High velocity input prevented stratification and reduced efficiency.	Diffusers were installed to minimize velocity.
High Thermal Loss in Buried Tank	Water getting into insulation of buried tank increased heat loss.	Provide ground water drainage, provide waterproof insulation, or locate above ground.
Heat Loss	High heat loss at night was thought to be through the tank insulation due to high ground water. Further investigation showed a faulty thermocouple that allowed pump to run all night, rejecting tank heat to atmosphere.	Thermocouple was replaced and subsequently failed again. It was then found they were not suitable for the temperatures experienced and were replaced with high temperature thermocouples.
Heat Loss	Ground water around tank resulted in high heat loss.	Additional insulation and stones were placed under and around tank to improve drainage.
Bypass of Rock Storage	A rock storage bed designed for horizontal flow had an air space left at the top, which permitted the air to bypass the rocks.	Redesign to use vertical flow through the rock bed (horizontal flow also reduces the desired stratification effect).
Leakage	Leakage existed at fiberglass tank joints after tanks were assembled on site from two halves.	Careful assembly following the manufacturer's recommendations using the recommended sealing materials is required.
Leakage	Fiberglass tanks leaked through "wicking" action in some fiberglass threads that extended through the tank.	Seal all exposed fiberglass threads.

TABLE 4. STORAGE PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Sewer Gas in the House	A sewer drain was installed under a rock storage bin to remove any water. The heat in the bin evaporated the water in the drain trap, letting sewer gas into the house.	Changed drain to a location outside rock bin.
Heat Loss Through Insulation	Buried concrete tank leaked water through the tar seal, soaking the insulation and increasing the heat loss.	Changed to above ground storage tank.
Heat Loss	Heat loss from domestic hot water tanks exceeded manufacturers specifications. Investigation showed the added solar piping and instrumentation provided an increased heat leak path.	Adequately insulated all exposed piping and instrumentation connected to the storage tank.
Oversized Storage Tank	Tank was too large for collector area and tank temperature never exceeded 57°C (135°F).	Replaced tank with one that provided 7.6 liters (2 gallons) of storage for each square foot of collector.
Contaminated Heat Exchangers	Heat exchangers supposedly of refrigeration quality were contaminated with machine oil and metal filings.	Units were returned to vendor for cleaning.
Heat Transfer Losses	Heat transfer from collector loop through the heat exchanger into the storage tank was not as good as assumed.	A parallel heat exchanger was added. (This was considered less expensive than replacing with a more desirable larger single heat exchanger.)

TABLE 4. STORAGE PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Corrosion	Investigation indicated that the corrosive condition of the ground itself might create problems with the underground storage tank.	Installed cathodic protection for the tank (sacrificial magnesium anodes) and coated tank with a rubberized vapor barrier.
Heat Loss	Steel legs supporting storage tank were a major conductor of heat.	Thermally isolated supporting legs.
Heat Loss	Underground tank insulation was damaged due lack of proper support in rocky soil. Maintaining watertight insulation on underground storage tanks is difficult. Water in insulation increased heat transfer.	Check waterproofing prior to installing, provide proper support, install carefully, patch any bad spots in insulation, and backfill carefully.
Incorrect Inlet and Outlet	Flow from collector to tank entered at bottom of tank. Flow back to collector was also from bottom of tank causing short circuit in flow path and eliminating benefit of stratification.	Flow from collector to tank should enter tank at top where water is hottest. Flow back to collector should be from bottom of tank (on opposite end from inlet if no distribution manifold is used).
Materials	Material planned for inside coating of storage tank melted at 82°C (180°F).	Changed to a compound stable at 145°C (250°F).
Saturation of Insulation	An open-cell foam was applied to the tank due to lack of product research. This acted like a sponge, collected water, and increased heat loss.	Use closed-cell foam.

TABLE 4. STORAGE PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Too Many Tank Penetrations	The fiberglass storage tank had all feed and return pipes for the solar loop, house loop, and domestic water loop through the tank below the water level. This resulted in leaks that were difficult to seal.	Two of the three loops were pressurized with positive pressure to the pump suction. Only suction line to the unpressurized loop needed to be below the water level to provide positive suction to the pump. All others could be brought into the tank above the waterline, and even the one suction line tank penetration could be above the water level if a foot valve was added.
High Pressure Drop in Heat Exchanger	Heat exchanger tubes extended completely through manifold to far side of manifold and restricted flow.	Reworked manifold header to provide internal clearance.
Loss of Heat from Storage	A heat exchanger for collector to storage heat transfer was installed too high in the storage tank. Under some conditions (particularly at lower insolation), the collector pump would start when collector temperatures were below storage tank top temperatures resulting in transfer of heat from storage to collector.	Ensure proper location of heat exchangers and proper location and setting of controls.
Trash in Tank	Tank covers were difficult to remove to check water level and loose tank insulation was dislodged and dropped into tank.	Covered source of loose insulation and used care in opening.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Control	A system that had been operating properly began to pump heat from the storage tank to the collectors. Investigation showed some corrosion in the sensor in the storage tank had changed its operating temperatures.	Changed sensor. Proper maintenance and frequent inspection is required.
Control	The collector temperature sensor was mounted on a pipe outside the collector and did not measure the actual collector temperature, resulting in poor performance.	The sensor was moved to a pipe inside the collector adjacent to the absorber plate.
Control	A sensor was improperly mounted and only had minimum contact, resulting in poor performance.	The sensor was properly clamped to the pipe.
High Pressure Drop in System	Liquid heat exchangers exceeded back pressure levels advertised by manufacturer.	Units were modified to reduce pressure drop across them.
Freezing of Collectors	Power failure prevented pump from circulating warm water from storage when freezing conditions existed.	Backup drain system was added to provide alternate freeze protection method.
Freezing of System	During installation, water was used for testing in lieu of the ethylene glycol solution specified for system operation, resulting in freezing.	Test with the specified fluid or ensure complete drainage of water if possibility of freezing exists.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Freezing of Air to Water Heat Exchanger in Air System	Leaking dampers permitted thermosyphoning of air from the collectors on cold nights that froze and ruptured the heat exchanger pipes.	Adjusted dampers to ensure proper sealing to prevent unwanted air movement.
Trash in System	Small passages in collectors were clogged with trash.	Flush system and collectors prior to completing hookup. At startup, circulate fluid through filters.
Insulation Deterioration	Weather-exposed rubber type insulation deteriorated due to ultraviolet radiation.	Use protective paint (not always effective), a weather proof cover, or a different type insulation.
Poor Dampers Resulted in Air Loss	Back flow of air into collectors when furnace was on was due to "home-made" dampers. These had to have excessive clearance on the edges to operate in an uneven duct and did not seal when closed.	Changed to dampers that had flanges and seals to close against for positive sealing.
Operation of System Was Not as Designed	Investigation of operating modes revealed some sensors were as much as 8.3°C (15°F) out of manufacturer's specifications.	Check temperature sensors if control problems exist.
Hose Failures	Rubber hose connections exposed to sunlight developed cracks and leaks in 6 weeks.	Use material that does not deteriorate with exposure to ultraviolet radiation.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Increased Cooling Load	Heat loss from solar storage in basement added to the summer cooling load in the building.	Provide adequate insulation and exhaust unwanted heat to atmosphere.
Fan Motor Overheating	Collector to space heat exchanger was placed upstream of space distribution fan and motor, resulting in fan motor operating temperatures in excess of design limits.	Place solar heat exchanger downstream of space distribution fan or ensure fan operating limits are adequate for temperatures.
Safety Requirements	Certain types of glazing and insulation materials do not meet flame spread requirements of applicable codes.	Ensure materials used meet flame spread requirements, if this is an applicable criterion.
Collector Freezing	A check valve installed to prevent thermo-syphoning did not seal and collector froze.	Ensure proper operation of check valves.
Domestic Hot Water Usage	A preheater tank in the domestic hot water system was used to store solar energy. The water in the tank then flowed through the regular electric tank. If little water was drawn, the electric power maintains the temperature in that tank and little benefit is gained from solar heating.	Evaluate the water consumption to determine the best system design. Put solar heat into a preheater tank or directly into the electrically heated tank.
Loss of Pump Prime	Pump was installed above tank in an unpressurized system and lost prime at times.	In unpressurized system, install pump where adequate supply is available.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Excessive Power Requirements	Due to some uncertainties as to pressure drop in the system, an oversized pump was installed. This resulted in reduced system efficiency.	Size system components for actual requirements.
Improper System Control Sensor Location	Liquid and rock storage containers tend to stratify, with a considerable temperature variation possible. The installed control can thus be in a hot or cold area, depending on the location.	Ensure that control sensors are located in the storage area that will produce the desired results.
Air Leakage	Back-draft dampers were found to be binding and not operating properly.	Provide proper clearance.
Piping Leakage	Many piping leaks have been found in systems. These are more evident in oil systems, as water leaks may evaporate.	Soldered connections are preferable to threaded connections. Good workmanship is required.
Freezing	The sensor to initiate freeze protection was in a collector and check valves were installed in the line to prevent thermosyphoning. Despite check valves, convection loops developed within the downcomer pipe that caused the adjacent freeze sensor to indicate 27°C (80°F) when ambient was actually -6°C (20°F).	Freeze sensor was relocated to an area that could not be affected by the convection loop.

TABLE 5. SYSTEM PROBLEMS		
PROBLEM	**DESCRIPTION**	**RESOLUTION**
Control Strategy	During a warm evening, simultaneously the chiller was taking heat from storage to operate, the auxiliary boiler was operating and putting heat into the building, and the collector pump was operating and rejecting heat from storage to the sky.	Analysis of control requirements, development of proper control strategy, proper location of control sensors, and proper setting of controls is required for correct system operation.
Air Pockets	System installation had a number of air pockets that reduced efficiency.	Additional air vents were added. Proper design and installation would have eliminated this problem.
Unnecessary Piping	A large system had a number of redundant pipes.	Design was simplified to eliminate redundant piping.
Water in Nitrogen System	Large system with drain down refilled at different rates in rows forcing water into the nitrogen purge lines.	Install special valves in nitrogen lines that will not pass water.
Air Bubbles in System	Large system took 1 week after startup to get all air bubbles out of water. When water/glycol was introduced, it took over 1 month to get all bubbles out.	Allow time to get all air out of system (problem may have been complicated by faulty outlet location in collector causing air entrapment in collector panel). Consider evacuation of air prior to filling.
Increased Cooling Load	Heat from cooling equipment was rejected into mechanical room and increased cooling load.	More insulation on equipment.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Failure of Pump Seals	Tungsten carbon seal failure in pump was attributed to corrosion in system.	Use seals compatible with system fluids and materials.
Pressure Relief Settings	Pressure relief on collectors and boilers mismatched.	Correct settings.
Control Instability	Pumps and fans cycled frequently at startup and shutdown, reducing solar energy collection and decreasing motor life.	Increase control differential and/or add time delays and/or move control sensors.
Corrosion	Corrosion found in tank and transport system after a long period of operation.	Corrosion evaluated and the proper inhibitor added.
Algae Buildup	Algae found in tank and transport system after a long period of operation.	Algae evaluated and the proper biocide added.
Pump Failure to Start	Thermal overload on pump occasionally caused shutoff at start.	Adequate sizing of components.
Excess Heat Transferred to Building	An integral roof collector had back panel exposed to room causing excessive heat transfer into building in summer and overloaded cooling system.	Additional insulation added to back of panels.
Expansion Tank Size	Expansion tank was undersized and had insufficient volume for fluid when hot.	Replaced with larger expansion tank.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Pump Control	Pump control did not adequately control flow rate through large banks of collectors, resulting in loss of system efficiency.	Proper sizing of pump, proper controls, and balancing of collector arrays for proper flow rates.
Pump Location	Pump on downstream side of collector in unpressurized system had tendency to cavitate.	Located pump at low point in system such that pump was pumping from tank and through collector.
Pump Seal Failure	Seals failed in ethylene glycol solution due to material incompatibility	Changed to oil transport medium and seals compatible with the oil.
Roof Penetrations	System design required 170 roof penetrations.	Redesign of support frames and piping significantly reduced roof penetrations.
Pipe Heat Loss	Planned use of asbestos cement pipe permitted high heat loss in transport system.	Changed to conventional pipe with insulation to reduce heat loss.
Shading of Collectors	Significant shading from nearby buildings and trees would occur December through January.	Moved site. In planning for system, the shading profile must be investigated (daily and seasonally).
Specifications	Specifications were inadequate for bidding and contracting for installation.	Improved specifications and details.
Roof Leakage of Internal Collector	Collector was also the roof and leakage was directly into the building.	Improved design to ensure no leakage around collector.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Air Leakage	Moveable dampers had considerable air leakage in the closed position.	Proper adjustment of damper linkage.
Unstable Controls	A bad control caused circulation of water to collectors at night, with consequent loss of stored heat.	Controls were checked and problem corrected. Frequent maintenance checks are necessary to find such problems.
No Air Flow	Installation space required blower modifications. In the reassembly, the squirrel cage fan was installed so that it ran in the reverse direction.	Reversed fan.
Draining/Boiling	A high temperature collector was installed to be compatible with a cooling subsystem to be added later. Stagnation temperature was over 315°C (600°F) but collector could not be drained without partial disassembly. Attempting to drain by boiling off through vent valves left a residue.	Use a purge system during the summer (which is expensive), install the cooling units at original system installation so collectors can be used in the summer, or install curtain covers.
Tracking Failure	Tracking mechanism had frequent failures due to electronic component problems caused by instantaneous motor reversal.	Redesigned electronic components.
Tracking failure	Binding in the tracking mechanism caused overheating of the drive motor.	Redesign of tracking mechanism and addition of an oiling mechanism.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Fuses Blowing	Fuses blew every four to five days on random basis, believed to be due to rapid cycling of air handling motor from passing clouds. Lack of time between starts to dissipate heat in the fuses caused by starting surges eventually caused fuses to blow.	Time delay switch placed in circuit to allow preset time interval between starts.
Balancing Collectors	No provision was made to balance banks of collectors, which reduced efficiency (some banks ran hotter).	Provide adequate means to balance banks and panels, and a means to determine the balance.
Boiler Pressure Relief Valve Opening	Sudden pressure in the long line caused the line valve to open producing a large surge of water into the boiler, lifting the relief valve.	A motorized valve was installed to produce a gradual increase in flow rate.
Liquid Flow Rates	To optimize performance, it was desirable to supply solar heated water directly from the collectors to heating units. However, the designed flow rates in collectors and conventional heating systems differed.	Careful sizing of components is required to match collector and heating system flow rates.
Freezing	A glycol solution became "slushy" at its low temperature limit and prevented flow through the system until the morning warming. On one sunny day pressure increased in the thawing collectors faster than the rate of thawing in pipes. Flow from the collectors to the relief valve was prevented, bursting collectors.	Increased glycol concentration sufficiently to maintain solution above freezing point at lowest expected temperature.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Filling Procedures	Filling liquid systems with the glycol-water solution did not proceed smoothly due to insufficient pumping capacity and halts to mix solution. The solution boiled in collectors under the existing insolation, generating low pressure steam that prevented completion of filling.	Fill system in the early morning prior to higher insolation rates or cover collectors.
Thermosyphoning	Thermosyphoning occurred in an air system due to lack of backdraft dampers. This resulted in hot air rising from the storage bed to the collector at night and heat was rejected to the atmosphere.	Installed backdraft dampers.
Air Venting	A domestic hot water system that did not have a heat exchanger but did drain down for freeze protection had air trapped in the system when it refilled, even though an air vent was provided.	Air vent was moved from the high point on the collector to the location where the air was forced when the pressurized water reentered the collectors.
System Cycling	On a cloudy day, air system was cycling on and off. Investigation showed heated air from the auxiliary furnace was leaking into the collectors, causing a temperature differential that started the solar system.	Installed backdraft dampers.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Corrosion	Threaded iron fittings were used on copper pipes, which resulted in extensive corrosion and partial blocking of the flow passage.	Use only copper fittings with copper pipe.
Flow Rates	Excessive flow rates reduced system efficiency.	Throttled flow rate to improve performance (smaller pump is preferred solution).
Heat Exchanger	Heat exchangers had higher back pressure than manufacturer's specifications, causing reduced flow rates.	Changed heat exchanger.
Pressure Drop	Larger than anticipated pressure drop in system caused reduced flow rates.	Added pump in series.
Clogged Furnace Blower	System air flow rates were less than anticipated. Investigation showed that the regular air distribution fan was badly clogged and affected the solar blower.	Cleaned fan.
Control	Air collector system fan started when collectors were colder than house. Investigation showed that controls were wired to turn system on when collectors were 11°C (20°F) warmer than storage (regardless of storage temperature) and then would circulate directly to the house.	Sensor added to inhibit system operation if collectors were less than 38°C (100°F).

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Freezing	A water/glycol collector system had an external heat exchanger in the basement that froze. Investigation showed that the water on the storage side of the heat exchanger (and the warmer basement) heated the collector fluid sufficiently to start thermosyphoning. This brought a solution at less than 0°C (32°F) into the heat exchanger and froze the water side.	Install a check valve in the collector loop to prevent thermosyphoning or circulate water from storage to keep heat exchanger warm.
Control	System cycled on and off during periods of low insolation. Investigation showed control sensor had been moved by a plumber during repairs.	Replaced sensor in proper location.
Sensor Capacity	Absorber plate sensor failed because temperature exceeded design limits.	Replaced sensor with one designed for high temperature use.
Control	Collector pump cycled on and off at 5°C (10°F) differential. Time delay did not cure problem.	Changed to 10°C (20°F) differential sensor and moved sensor to bottom of tank.
No Collector Air Flow	Relay which controlled the air dampers failed. Relay was located inside the air handler where temperatures exceeded relay design limits.	Replaced with relay designed for higher ambient temperatures.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Controller Failure	Controller components were improperly packaged in the control box and removal of the cover for adjustments damaged them.	Replaced controller.
Control Logic	Control was designed to heat building direct or from storage if there was adequate heat, and the auxiliary system only operate if there was inadequate heat. A failure in the solar transport system would result in no heat from auxiliary to building if there was solar heat available.	Changed to a two stage thermostat that would provide heat from auxiliary if the solar heating failed to operate for any reason.
Improper Connections	A vertical heat exchanger in the storage tank was inadvertently connected by the installer so that the hot return from the collector went to the top of the heat exchanger.	Changed piping so that the return from the collector entered the heat exchanger at the bottom of the tank.
No Intake Screen	Pipe for pump suction in the storage tank did not have screen; consequently, there was a possibility that trash could be drawn into pump.	Installed screen at intake.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Condensation	A tank in a storage shed had a loose fitting convex manhole cover with a lip on the outside of a coaming, a hole through a cover for the fill line, insulation around the tank, and an access "tunnel" to the manhole cover. With no insulation in the tunnel, condensation formed on the underside of the cover and ran down the outside of the tank. When insulation was placed in the tunnel, moist air from the fill line hole condensed in the insulation and soaked it.	The loose fitting cover was replaced with a sealed cover, and a separate vent was led to the outside of the tank.
Sensor Failure	A storage tank float sensor for a low water level indicator light failed. Investigation showed it to have open contacts that had corroded in the moist environment in the storage tank.	Changed to a mercury contact sealed sensor on the float.
Flow Bypassed	When the cold water supply was piped to the cold water inlet at the top of the domestic hot water tank, and this same inlet was used to supply the collector pump, a hot water draw would cause the incoming city water to flow through the collector instead of through the tank because the tank had a higher head pressure than the collector.	Changed piping so the city supply went through the tank top, but the collector supply came from the bottom outside the tank.

TABLE 5. SYSTEM PROBLEMS

PROBLEM	DESCRIPTION	RESOLUTION
Thermosyphoning	In an attempt to reduce installation costs, the supply for the collector pump was taken from the cold water inlet at the top of the domestic hot water tank. Although check valves were in the system, thermosyphoning developed in the direction of flow. Investigation showed that the cold water tube to the bottom of the tank had a small hole near the top as an antisyphoning device under normal use, but which permitted thermosyphoning in the system as piped.	Changed piping so collector supply came from the bottom of the tank and was outside the tank. This also improved collector efficiency as the original hook up permitted as much as a 15°C (27°F) gain from the tank in the supply temperature to the collector.

APPROVAL

HARDWARE PROBLEMS ENCOUNTERED IN SOLAR HEATING AND COOLING SYSTEMS

By Mitchell Cash

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

WILLIAM A. BROOKSBANK, JR.
Manager
Solar Heating and Cooling Project Office

☆ U. S GOVERNMENT PRINTING OFFICE 1978-740-193/431 REGION NO 4

DISTRIBUTION

INTERNAL

FA31
Mr. Brooksbank

FA02
Mr. Nicholson (50)

FA32
Mr. Marshall
Mr. Cash (50)

FA33
Mr. Myers (20)

EE01
Mr. Richardson (10)

EP45
Dr. Littles
Mr. Simon (10)
Mr. Parker

EL55
Mr. Stonemetz (10)

EH43
Mr. Roberts

EC24
Mr. Jones

CC
L. D. Wofford, Jr.

AS61 (3)

AS61L (8)

AT01

EXTERNAL

NASA Scientific and Technical Information
Facility (25)
P.O. Box 8757
Baltimore/Washington International Airport
Baltimore, MD 21240

Department of Energy
Attn: Mr. Corcoran
Mr. LeChevalier
20 Massachusetts Avenue
Washington, D.C. 20545

University of Alabama in Huntsville
Johnston Environmental and Energy Center
Attn: Mr. Christensen (10)
P.O. Box 1247
Huntsville, AL 35807