CONF-800103--3

APPLICATION OF RELIABILITY, MAINTAINABILITY, AND AVAILABILITY ENGINEERING TO SOLAR HEATING AND COOLING SYSTEMS

by

Prem S. Chopra and Ronald M. Wolosewicz

MASTER

Prepared for

1980 Annual Reliability and Maintainability Symposium

San Francisco, California

January 22-24, 1980

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

U of C-AUA-USDOE

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Operated under Contract W-31-109-Eng-38 for the

U. S. DEPARTMENT OF ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) among the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona
Carnegie-Mellon University
Case Western Reserve University
The University of Chicago
University of Cincinnati
Illinois Institute of Technology
University of Illinois
Indiana University
The University of Iowa
Iowa State University
The University of Kansas
Kansas State University
Loyola University of Chicago
Marquette University
The University of Michigan
Michigan State University
University of Minnesota
University of Missouri
Northwestern University
University of Notre Dame
The Ohio State University
Ohio University
The Pennsylvania State University
Purdue University
Saint Louis University
Southern Illinois University
The University of Texas at Austin
Washington University
Wayne State University
The University of Wisconsin-Madison

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights. Mention of commercial products, their manufacturers, or their suppliers in this publication does not imply or connote approval or disapproval of the product by Argonne National Laboratory or the United States Government.

Application of Reliability, Maintainability, and Availability Engineering to Solar Heating and Cooling Systems

Prem S. Chopra, PhD; Argonne National Laboratory; Argonne

Ronald M. Wolosewicz, PhD; Argonne National Laboratory; Argonne

Key Words: Solar-energy systems, Reliability estimates, Availability methodology, Field information, Failure rate, Fault trees, FMEA.

Abstract

This paper compares the reliability of solar hot-water and heating systems with that of conventional systems using block diagrams, failure modes and effects analysis, and fault trees. Although stand-alone solar-energy systems are not as reliable as conventional systems, the RMA of the combined solar and conventional system can be made comparable to currently available heating and hot-water systems. An availability matrix is presented that can be used to develop maintenance schedules that do not decrease the system's availability. Field data presented on operating solar heating and cooling systems indicate that these systems experience four major generic problems: freezing, leakage, controls, and collectors.

Introduction

A major objective of national energy planners is the early commercialization of solar heating and cooling systems for buildings in order to replace nonrenewable energy sources currently being utilized for these functions. To achieve this objective, solar-energy systems must be cost-effective and reliable and must foster consumer confidence. They must demonstrate high reliability (relative ease of maintenance and repair), and availability (relative trouble-free operation) as compared with conventional heating and cooling systems.

Economic considerations are also a significant factor in commercialization. These involve the initial costs of the system, its operational costs (including the costs of unreliability, maintenance, and unavailability), and the thermal efficiency of the system when it is operating. Successful commercialization of solar-energy systems, therefore, requires that system goals be established for costs, for operational reliability, maintainability, and availability (RMA), and for thermal performance. This paper deals with the application of established RMA techniques to solar heating and cooling systems. These techniques can allow realistic RMA goals and procedures to be established for the design of reliable systems, for RMA trade-off studies, for life cycle costing, and for operation and maintenance.

The paper presents examples of reliability assessments of solar hot-water and heating systems using system block diagrams, failure modes and effects analysis, and fault trees. Results of these assessments are compared with those for similar conventional systems.

Most of the component failure rate data used in these assessments were obtained from similar components used in nonsolar applications. Since some components used in solar heating and cooling systems are unique and others experience a unique operating environment, it is necessary to obtain reliability and maintainability data from operational solar-energy systems. Such data are being collected and evaluated by Argonne National Laboratory's (ANL) Solar Reliability and Materials Program on systems sponsored by the Office of Solar Applications of the United States Department of Energy (DOE) (Ref. 1).

Solar-Energy System Reliability Assessments

The most commonly used reliability assessment techniques are block diagrams, failure modes and effects analysis, and fault trees. In this section, these techniques are applied to solar hot-water systems, solar space heating systems, and conventional systems, and their relative reliabilities are compared.

Domestic Hot-Water System Reliability Analysis

The application of the block diagram technique is illustrated with a domestic hot-water preheating system. In this example, only one component--the pump-- is considered in the reliability design trade-off.

Figure 1 illustrates the system installed at one of the residential solar demonstration sites. From this schematic, the reliability block diagram shown in Fig. 2 can be prepared. By assuming constant component failure rates, the system reliability, R_s, is expressed in Eq. 1 as:

$$R_s = R_1R_2R_3R_4R_5R_6 \tag{1}$$

where:

R_1 through R_6 are the reliabilities of the individual components.

For constant failure rates, the component reliability is:

$$R_i = \exp\,(-\lambda_i t) \tag{2}$$

and the system reliability, R_s, is

$$R_s = \exp\left[-(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)t\right] \tag{3}$$

Component failure-rate data for this assessment are presented in Table 1. These data were compiled from various nonsolar sources and the collector-loop-pump

Table 1. Failure Rates of Components for DHW System Per 10^5 Hours

Component	Failure Rate
Collector	1.141
Collector Piping	1.058
Controller	1.40
Collector Pump	30.0 (high)
	3.349 (median)
	0.30 (low)
Piping System	0.30
Check Valve	0.301
Water Heater/Storage Tank	0.571

$$R_{prs} = \left[2-\exp(-\lambda_3 t)\right]R_s \quad (4)$$

$$R_{srs} = (1 + \lambda_3 t)R_s \quad (5)$$

where:

R_{prs} is the system reliability with a parallel redundant pump,

R_{srs} is the system reliability with a standby redundant pump,

R_s is the original system reliability, and

λ_3 is the failure rate of the pump.

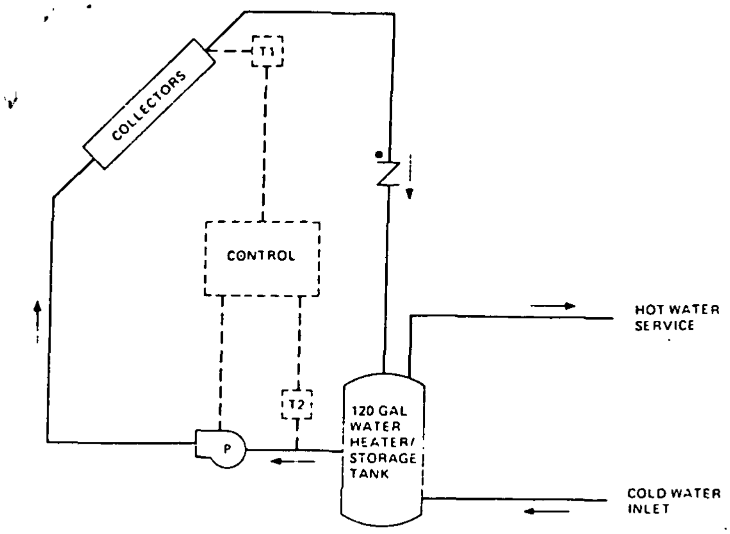

Fig. 1. Schematic of a Solar Hot Water System

failure-rate data were obtained from the nonnuclear portion of WASH 1400 (Ref. 2). The failure rate of the collector was estimated by assuming that the single collector panel would last twice as long as the warranty. Therefore, the rate was set at one failure in ten years. This failure rate was used by Chun in an earlier study (Ref. 3).

Given the component failure-rate data, Eq. 3 can be evaluated for various time intervals, and the resulting reliability curves are presented in Fig. 3. For comparison purposes, this figure also presents the estimated reliability of a conventional domestic hot water (DHW) system. Results for the conventional system were obtained by setting the failure rates of the solar-related components in Eq. 3 to zero.

The reliability results shown in Fig. 3 indicate that the conventional DHW system is more reliable than the solar DHW system. Only when the low or median failure-rate pumps are used does the reliability of the solar-energy system begin to approach the reliability of the conventional system. Hence, the following discussion will concentrate on low and median failure rate pumps.

The mean-life of a solar DHW system having a pump with a median failure rate is estimated at 12,300 operating hours. A pump with a low failure rate will increase the system's mean-life to 19,700 operating hours. However, the estimated mean-life of a conventional DHW system is approximately 67,000 operating hours. The reliability level of the solar DHW system can be increased by installing a second pump in either a parallel or a standby configuration. For these two cases, the system-reliability block diagram in Fig. 2 now includes the block for the second pump, represented by dashed lines. Equations 4 and 5 are the governing equations:

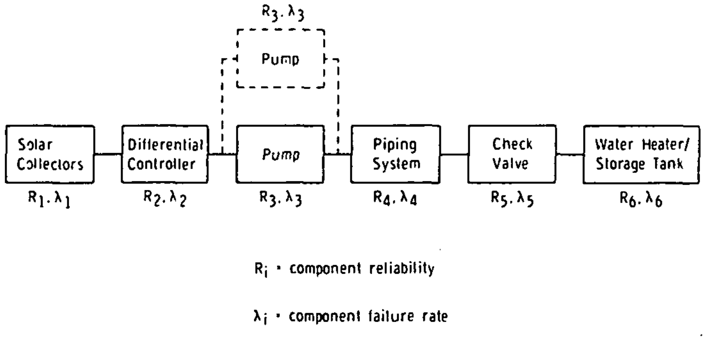

Fig. 2. Reliability Block Diagrams

The reliability curves for the redundant pump configurations and for a conventional DHW system are presented in Fig. 4. This figure also includes the results for the median and low failure rate pumps. Although the reliability of the solar-energy system has increased, it is still less than that of the conventional system.

A standby configuration that has pumps with median failure rates ($\lambda = 3.35 \times 10^{-5}$/hr) will give the same reliability as a single pump with a low failure rate ($\lambda = 3.0 \times 10^{-6}$/hr). Furthermore, the difference in reliability between the system with a standby pump and the one with a parallel pump after 10,000 hours of operation is only 4%. Thus, the choice between installing a redundant median failure rate pump configuration and installing a single pump with a low failure rate becomes one of design preference or economics.

Results covering several of the components that are critical to the systems, as presented in Figs. 3 and 4, enable the designer of solar-energy systems to evaluate various component and system options. Cost-benefit studies leading to the design of the most cost-effective system configurations on a life-cycle basis can be conducted. For example, the following questions can be raised. At a specified reliability level, is it more cost-effective to install two pumps and delay maintenance than to rely on a single pump that will require more frequent maintenance? For a specified reliability level, when should maintenance be performed?

Failure Modes and Effects Analysis

Failure modes and effects analysis (FMEA) is particularly applicable to solar heating and cooling installations because, in general, these systems do not have redundancies to avoid single failure modes.

FMEA was used to evaluate the reliability characteristics of four control systems used on solar-energy heating projects (Refs. 4, 5). The results of these analyses for two solar-energy systems using air as the heat transfer medium are presented and are used to characterize the control systems for the fault tree evaluations of the overall solar-energy system.

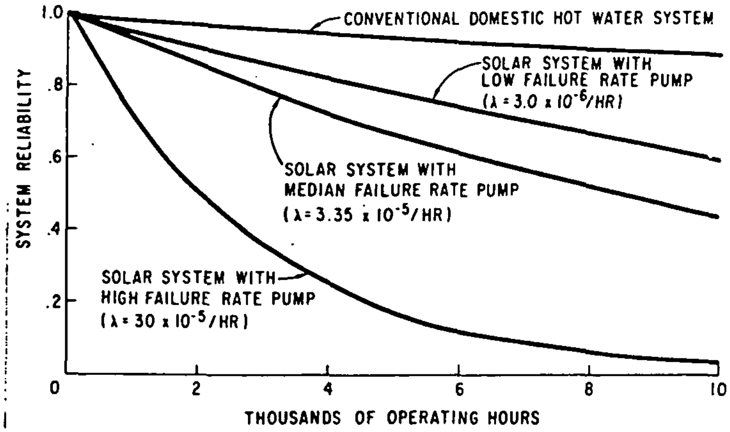

Fig. 3. Effects of Pump Failure Rate

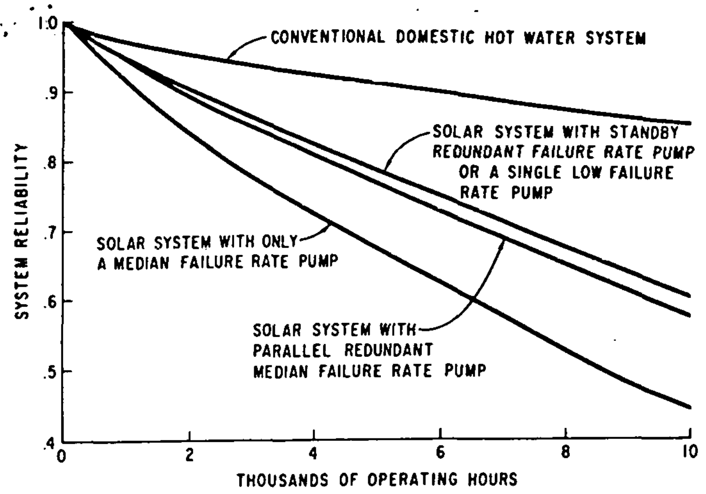

Fig. 4. Benefits of Using a Redundant Pump

Solar-energy systems using air as the heat transfer medium have at least the following operating modes: collectors to space heating, storage to space heating, and collectors to storage. If a domestic hot water preheating option is included, an additional operating mode is possible.

The FMEA results in this paper are based on non-solar data of the type shown in Table 2 (Ref. 2). These failure data, including demand and operating failure rates, were combined using the averaging technique in Reference 6. Based on the availability of solar energy and the demand for heat, the control system switches between the three operating modes. Therefore, to obtain an average failure rate for the control system, the failure modes were weighted by the fraction of time each mode was operating.

FMEA data in Table 3 indicate that both control systems have comparable overall failure rates. The slightly lower failure rate for the system located in the northeast can be attributed to the use of fewer components and digital integrated circuits for the control logic. The control system at the midwestern site uses electromechanical relays for the logic functions and these elements have higher failure rates than well-designed integrated circuits. In future solar energy systems, if these electromechanical relays are replaced with solid state units, the reliability of the control system will probably increase.

Fault Tree Analysis

Fault trees have been constructed and used to assess the reliability of air-cooled solar-energy systems (Ref. 5). These trees are not complicated and usually contain one "OR" gate and the component-oriented initiating events. The data inputs for evaluating the trees were obtained from various nonsolar sources and

Table 2. Control System Component Demand and Operating Failure Rates

Component	Demand Failure Rate, per 10^4 Demand	Operating Failure Rate, per 10^6 Hours
Thermistor	-	1.0
Relay	1	10
Motor Starter	1	10
Transformer	-	1.0
Fuse Open	-	1.0
Fuse-Fails to Open	-	10
Thermostat	1	0.3

Table 3. Comparison of Failure Rates for Two Solar-Energy Control Systems per 10^5 Hours

System Location	Mode 1	Mode 2	Mode 3	Overall
Midwest	20.8	0.38	20.8	8.55
Northeast	0.65	3.41	5.23	3.23

are presented in Table 4. This table also contains the results for the control system FMEAs.

The effective failure rate for the collector array was estimated using the partial redundancy technique where k out of m collector panels must be available for the system to operate successfully (Ref. 8). This approach was chosen because, if the collector array were represented as a series model, then the failure rates would be on the order of 10^{-3} per hour. In contrast a maximum redundancy parallel model where only one of the m collector panels must be available for the system to operate successfully would not be representative of field conditions.

The partial redundancy procedure was programmed and used to provide the collector failure rate input for the fault tree analysis. The results of these system reliability calculations are presented in Figs. 5 and 6. For comparison purposes, the reliability estimate of a standard gas forced-air furnace based on the model in Reference 9 is also shown. The data for this model are presented in Table 5.

The reliability of the standard gas forced-air furnace as shown in Figs. 5 and 6 exceeds that of the two solar heated air systems. The lowest reliability of the solar-energy system occurs when the collector array reliability is approximately 0.40 at 5000 hours. Because of the assumption of parallel redundancy, this collector array reliability level requires that 95 percent of the collector array be available to supply the demand.

Table 4. Fault Tree Failure Rate Data Per 10^5 Hours

Component	Failure Rate
Collector	1.14 (One Panel)
Blower	0.27
Ducting	0.10
Motorized Damper	1.33
Storage	0.015
Control System	
•Northeast Site	3.23
•Midwest Site	8.55

Table 5. Gas Fired Forced-Air Furnace Failure Rate Data Per 10^5 Hours

Component	Failure Rate
Thermostat	0.061
Hot Air Sensor	0.33
Overheat Sensor	0.33
Plumbing External	0.023
Control Valve	0.50
Burner	0.57
Pilot-Light Sensor	0.33
Blower	0.27
Ducting	0.10

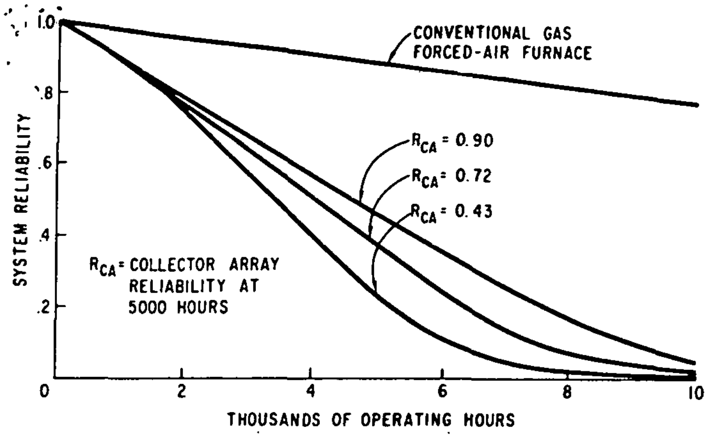

Fig. 5. Reliability of a Solar Air System in the Midwest

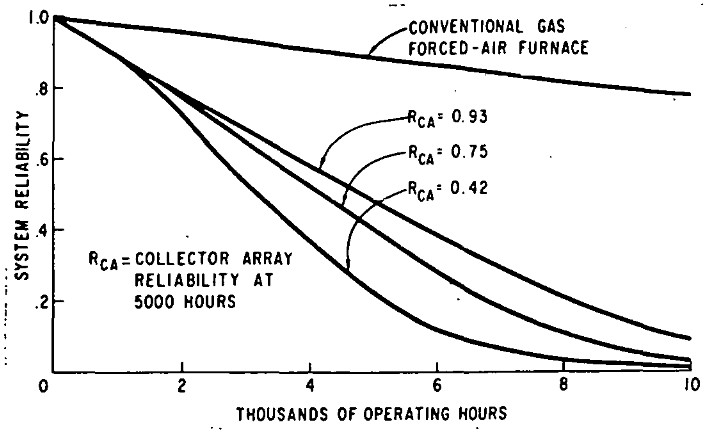

Fig. 6. Reliability of a Solar Air System in the Northeast

A more realistic system reliability estimate is obtained by assuming a collector array reliability of 0.90 at 5000 hours. This assumption implies that 10 percent of the collector array has failed or requires maintenance. The corresponding system reliability estimates are shown by the upper curves in Figs. 5 and 6.

These results indicate that the overall reliability of the solar air system is approximately 0.50 at 5000 hours. Even if the collector array was perfectly reliable at 5000 hours, the system reliability would be approximately 0.53. This low reliability estimate is primarily caused by the control system and the damper configuration.

If the failure rate of the damper could be reduced by an order of magnitude to 1.33×10^{-6} per hour, then the reliability of the solar-energy system increases significantly and begins to approach that of conventional systems. Overall system reliability is now governed by the control system, and as a result, the reliability of the solar-energy system in the northeast, which uses integrated circuits for the control logic, increases from 0.50 to 0.75 at 5000 hours. For the system in the midwest, the system reliability increases from 0.46 to 0.60 at 5000 hours.

Discussion of Results

The reliability estimates presented in this paper indicate that solar-energy systems are not as reliable as conventional DHW or forced-air heating systems. However, because solar-energy systems depend on the interaction among variable insolation rates, storage, and auxiliary systems, they can sometimes be repaired without decreasing the overall availability of the system.

The availability of a solar-energy system can be investigated by developing subsystem availability matrices similar to the one presented in Fig. 7 (Ref. 7). This matrix indicates that, as long as solar insolation is not available and a demand for heat does not exist, then the collector subsystem can be repaired without decreasing the overall availability of the system. More detailed studies along these lines are in progress and will be presented in future papers.

The reliability assessments presented in this paper are based on nonsolar data sources. The critical item in the DHW system was the collector loop pump and in the air-cooled systems the dampers and the controls were identified as the critical components. Until additional data are obtained, it is difficult to ascertain whether or not these situations are representative of operating solar-energy systems.

To quantify the actual reliability and maintainability of the DOE sponsored solar-energy systems and to improve the assessments of the type presented in this paper, the ANL Solar Reliability and Materials Program has a data acquisition activity. Reliability and maintainability forms have been prepared for DOE and distributed to the DOE solar demonstration program contractors. A toll-free number is available for the contractors to report system success as well as problems. Additional field information is obtained by site visits, by reviewing contractor's reports, from thermal performance reports developed by the National Solar Data Network contractor, and DOE project summaries.

As field information is obtained, it is logged into the ANL Solar Reliability and Materials Library. These data are being evaluated to estimate component failure rates and to provide reliability statistics for future evaluations. Some of the library information is presented in the following sections.

Reliability Information from Operational Systems

The results of a review of 66 DOE-sponsored solar heating and cooling systems are presented in Fig. 8 (Ref. 10). These data were collected between April 1977 and April 1979. They indicate that three generic problems affect the performance of solar-energy systems. Detailed evaluations of these generic problems have been completed (Refs. 4, 11, 12).

System Freezing

Solar heating and cooling systems can freeze for a variety of reasons. A flow chart was developed in Reference 11 to present a composite picture of why some

		SOLAR ENERGY AVAILABLE	
		YES	NO
EQUIPMENT	YES	STATE 1	STATE 3
AVAILABLE	NO	STATE 2	STATE 4

State	Solar Subsystem	Time	Demand
1	Available	Up	Needed
2	Not Available	Down	Needed
3	Inactive	Idle	Needed/Or Not Needed
4	Not Available	Down	Needed/Or Not Needed

Fig. 7. Solar Collector Subsystem Availability Matrix

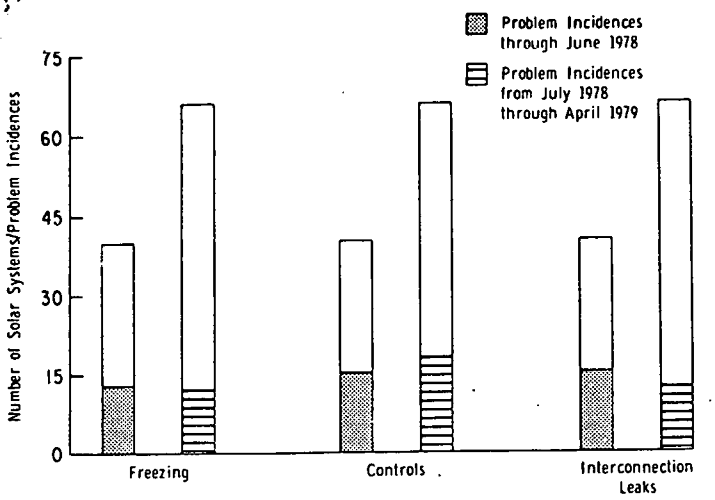

Fig. 8. Recorded Problems at Solar-Energy Sites

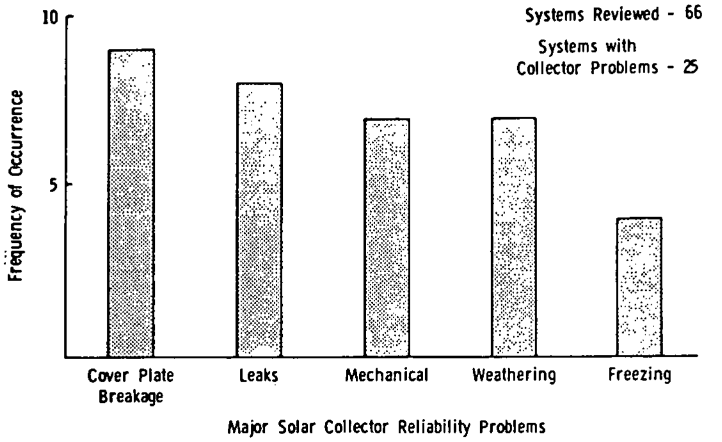

Fig. 9. Major Solar Collector Problems

of the air, water, and water-glycol systems froze. Many of the failures were documented and others were deduced by examing system schematics. Detailed recommendations to avoid freezing problems in solar-energy systems are presented in Reference 11.

Control Systems

Control system problems in solar heating and cooling systems arise because of the need to base control decisions on small temperature differences, the dependence on variable energy sources (solar insolation and storage), and the presence of auxiliary heating and cooling equipment. All of these parameters and the requirements to switch between various operating modes imply that solar-energy control systems are more complicated than those used to control conventional heating-ventilating and air-conditioning units. The use of FMEAs and the careful evaluation of truth tables can help to reduce the frequency of control system problems. Reference 4 summarizes the results of a review of 47 of the operational DOE-sponsored solar systems and presents guidelines for improving control system reliability.

Solar-Energy System Interconnections

The large number of connections between the collectors and the manifolds necessary on any solar-energy system implies that some interconnection devices can be expected to fail and some leaks can be anticipated. Many of the leakage problems can be traced either to improper elastomeric materials or to the use of screw-type hose clamps instead of constant-tension clamps. Material incompatibility has caused corrosion damage at several sites, requiring the retrofitting of pipes and flanges. Reference 12 reviews interconnection problems in detail and presents recommendations and guidelines for the system designer.

Solar Collectors

A review of 66 of the operational solar heating and cooling systems has shown that 25 of these systems experienced 47 different collector problems. Preliminary field data indicate that 35 of the 47 recorded collector problems can be placed in five major categories, as shown in Fig. 9. The remaining problems include buckling, condensation, lack of clearance, and dust collection on the collector glazing.

The five major collector problem types appear to be the result of poor design, thermal stress, failures, and stagnation. Preliminary information suggests that the causes are not independent. For example, sealing failures could have been caused by thermal stresses or design deficiencies.

Conclusions

Reliability assessment techniques such as block diagrams, FMEAs, and fault trees that are used in the nuclear, aerospace, and consumer product industries can be used to improve the reliability of solar-energy systems. If various design configurations are evaluated, cost benefit studies can be performed leading to the design of systems that are cost-effective over their lifetime. However, for meaningful reliability assessments and cost-benefit studies, component failure rates under appropriate operating conditions must be available, and an improved solar reliability data base must be established.

The field reliability information presented in this paper indicates that solar heating and cooling systems experience four major generic problems: freezing, leakage, controls, and collectors. Some data on the incidence of these problems are available, and additional data are currently being collected and evaluated.

The results of the reliability assessments presented indicate that stand-alone solar systems are not as reliable as conventional domestic hot-water systems (one failure in 13 years) or forced-air furnaces (one failure in 9 years). However, through proper interfacing with back-up or auxiliary systems, the RMA of the hybrid (solar and conventional system) can be made comparable to presently available heating and domestic hot-water systems.

The availability of the solar portion of the hybrid system can be increased by specifying more reliable components and by performing maintenance when there are no demands on the system. Therefore, the major challenge for the designer is to increase the availability of the solar portion of the hybrid system while still producing a cost-effective design.

Acknowledgments

The work described in this paper was performed under contract with the Department of Energy as part of the National Solar Data Program under the direction of H. Jackson Hale. The contributions of J. Mavec, P. Wang, E. Waite, and other members of the ANL Solar Reliability and Materials Program in conducting some of the studies presented in this paper are gratefully acknowledged.

References

1. P. S. Chopra, C. F. Cheng, R. M. Woloscwicz, "Preliminary evaluation of selected reliability, maintainability, and materials problems in solar heating and cooling systems," Argonne National Laboratory Report SDP-TM-78-2, Department of Energy Report SOLAR/0900-78/70, 1978 Sept.
2. "Reactor safety study: An assessment of accident risks in U.S. commercial nuclear power plants, Appendix III," U.S. Nuclear Regulatory Commission Report WASH-1400 NUREG 75/014, 1975 Oct.
3. Moon-Hyun Chun, "The use of event trees in solar heating system reliability assessments," special report to the National Bureau of Standards by the Korean Standards Institute, 1978 June.
4. E. Waite, et al., "Reliability and maintainability evaluation of solar control systems," Argonne National Laboratory Report SDP-TM-79-5, Department of Energy Report SOLAR/0903-79/70, 1979 March.
5. J. Mavec, E. Waite, R. M. Wolosewicz, "Reliability assessments of operational solar air systems," paper presented at the 1979 Operational Results Conference, Colorado Springs, Colo., 1979 Nov.
6. D. Kececioglu, "Lecture notes for the 16th annual reliability engineering and management institute," University of Arizona, 1978 Nov.
7. E. Waite, J. Mavec, P. Wang, R. M. Wolosewicz, "System reliability and solar system availability," informal notes presented at SERI Reliability Workshop, Denver, Colo., 1979 May.
8. W. H. Von Alven, ed., "Reliability engineering," Prentice-Hall, Inc., Englewood, Cliffs, N.J. (1964).
9. W. E. Jordan, "Failure modes, effects, and criticality analyses," Proc. 1972 Annual Reliability and Maintainability Symposium, 1972, pp 30-37.
10. P. S. Chopra, "Reliability and materials performance of solar heating and cooling systems," Argonne National Laboratory Report SDP-TM-79-8, Department of Energy Report SOLAR/0906-79/70, 1979 June.
11. P. S. Chopra, R. M. Wolosewicz, "Reliability and maintainability evaluation of freezing in solar systems," Argonne National Laboratory Report SDP-TM-78-3, Department of Energy Report SOLAR/0901-78/70, 1978 Sept.
12. J. Mavec, et al., "Reliability and maintainability evaluation of solar collector and manifold interconnections," Argonne National Laboratory Report SDP-TM-79-4, Department of Energy Report SOLAR/0902-79/70, 1979 March.

Biographies

Prem S. Chopra, PhD
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439 USA

Dr. Chopra is the Director of Energy Supply and Utilization Section in the Energy and Environmental Systems Division at Argonne National Laboratory. In his present position, he directs several programs in alternative energy technologies including the ANL Solar Reliability and Materials Program. Dr. Chopra's experience at Argonne includes management of reactor systems for the Safety Test Facility and supervision of structural and mechanical analysis sections for the Experimental Breeder Reactor. Prior to Argonne, he was associated with Boeing as a stress analyst, research engineer, and manager of fatigue and fail safety.

Ronald M. Wolosewicz, PhD
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439 USA

Dr. Wolosewicz is the Manager of the Reliability Engineering Group within the Energy Supply and Utilization Section. Prior to his present position, he developed a field testing program for electrically charged thermal energy storage units, participated in the ASHRAE subcommittee that developed a standard for these units, and was an editor of a solar thermal energy storage handbook. Before joining Argonne, he was a Senior Research Engineer at Whirlpool Corporation with internal consulting responsibilities in mechanical design and research in vibrations, structural analysis, viscoelasticity and porous bearings. He is a registered professional engineer in Illinois and was a Fulbright-Hayes fellow at the Institute of Basic Technical Problems of the Polish Academy of Sciences.