SERI/PR-351-419

November 1979

Systems Analysis and Testing (SAT) Program: Annual Progress Report October 1, 1978 - September 30, 1979

L.M. Murphy

Solar Energy Research Institute
A Division of Midwest Research Institute

1536 Cole Boulevard
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Operated for the
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price:
Microfiche $3.00
Printed Copy $4.50

SERI/PR-35-419
UC CATEGORY: UC-59,60,63

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ANNUAL PROGRESS REPORT

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L. M. MURPHY

NOVEMBER 1979

PREPARED UNDER TASK NO. 3525

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FOREWORD

The work discussed in this document has been performed as part of Task 3525, Systems Analysis and Testing. It reflects activities undertaken during fiscal year 1979.

Numerous individuals have assisted in the projects described herein. Approximately eight person-years have been focused on these projects. Efforts of the following people are reflected in this report: J. Anderson, C. Benham, C. Bingham, C. Bishop, J. Cohen, J. M. Connolly, A. Eden, G. Franta, R. Farrington, J. Henderson, J. Jayadev, C. Leboeuf, L. Morrison, L. M. Murphy, D. Noreen, F. Perkins, P. Steilstra, and J. Watkins.

Approved for:

SOLAR ENERGY RESEARCH INSTITUTE

Neil H. Woodley, Chief
Systems Analysis Branch

SUMMARY

The efforts of the Systems Analysis and Testing (SAT) Program in FY79 have resulted in many achievements in numerous technical disciplines. These achievements correspond to efforts in technical analysis and development as well as program definition, management, and coordination on a national level. The highlights of the FY79 achievements are the following.

- A comparative analysis of six generic water heating systems, recently completed, indicates strong performance/cost advantages of thermosiphon systems.
- A review of existing performance simulation models for wind, photovoltaics, and solar heating and cooling has been completed. Popularized brochures for each of these technologies have been published, and more than 7,000 of them have been disseminated.
- The SAT program has published 30 technical reports and papers during FY79.
- A comprehensive study of the effects of wind transients and of the control strategy on energy capture by Wind Energy Conversion Systems (WECS) has been initiated in FY79. Initial development of a real time analysis tool for WECS has been completed. An analysis of sampling-induced errors has been completed, which further demonstrates the need for such a tool.
- The following Management Plans have been prepared.
  - SAT Management Plan
  - Draft SAT Program Plan
  - Draft Integrated System Test and Validation Plan
  - Draft Plan for Analysis and Design Method Development
- The utility of a novel solar system diagnostic tool (thermography) has been demonstrated.
- Detailed and simplified simulation models which predict solar pond performance have been developed. Good correlation with initial simple experiments has been obtained.
- Novel stratified solar pond concepts using salts or membranes have evolved during FY79. Cost-effective applications for district heating have been predicted, and five publications have resulted.
- Validation of analysis methods has been given definition and direction by SAT efforts in FY79. Previous concepts have been assessed and reevaluated, and a new approach supported by simplified experiments has been proposed by SAT.
- A SERI Computational Methods Center was established, and procedures for the dissemination of computer codes were developed. The dissemination of F-Chart was begun.
- Technical management of DOE contracts in the SAT program was transferred to SERI. Statements-of-Work were developed for three new DOE contracts, and four procurement packages were developed for SERI-issued subcontracts.
- Forty-eight preliminary and formal proposals for DOE were reviewed by SERI.

- More than 1000 user technical inquiries on the use of F-Chart and SOLCOST have been answered.

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SECTION 1.0

INTRODUCTION

There currently is a recognized need to predict accurately the economic and energy use impacts of solar systems and to optimize various solar configurations, thus reducing energy costs. This need applies to a whole spectrum of users, including policy makers who are interested in sophisticated global systems analysis; researchers who are concerned primarily with innovative techno/economic issues; system analysts who bridge the gap between research and policy, marketing, and commercialization efforts; and solar system designers and users.

In late FY78, the Solar Energy Research Institute (SERI) accepted the responsibility for the development and management of the Systems Analysis and Testing (SAT) Program, a major program element of the National Solar Heating and Cooling Program within the R&D Branch, Conservation and Solar Applications, U.S. Department of Energy (DOE).

The overall objectives of the Systems Analysis and Testing Program are to:

- provide overall integration and direction to the Systems Development Division R&D effort;
- focus these efforts on the most effective aspects of product development/improvement; and
- provide the solar industry and others with methods to predict the performance of and to design/install/operate optimum solar systems.

Specific objectives of the Systems Analysis and Testing Program are to:

- identify and consistently rank solar technologies/systems which are optimized to the intended end use;
- identify cost/performance goals for various solar technologies/systems which make them competitive with conventional systems;
- develop and validate system simulation models, design tools, and handbooks for various user sectors;
- develop improved control strategies and control systems to increase solar system performance;
- coordinate/conduct system tests to evaluate, verify, and optimize system economic and performance behavior; and to develop data to use in the validation process;
- provide technical and management support, including planning assistance of a national scope; and
- disseminate the developed data and the tools to the user community.

This document describes SERI activities for the SAT program from 1 October 1978 through September 1979. The sections that follow discuss accomplishments in the areas of Systems Analysis, Systems Testing, Systems Validation, and Management Support.

SECTION 2.0

SYSTEMS ANALYSIS

The goal of this activity is to perform objective, consistent systems analyses of various solar systems and technologies. The development and dissemination of new simulation models for systems and components are an important part of this activity. Current SERI activities within the Systems Analysis area are described in the sections below.

2.1 REEVALUATION OF THERMOSIPHON DOMESTIC HOT WATER SYSTEMS

Side-by-side testing of six domestic hot water sytems by the National Bureau of Standards (NBS) had implied that thermosiphon systems are significantly out-performing other active systems being tested. As a result, SERI undertook a task to reevaluate the thermosiphon hot water system to assess its potential for offering significant cost and performance benefits over active sytems.

Findings of this study, based on an intensive literature search to locate side-by-side performance comparisons of thermosiphon and active hot water systems other than the NBS test, and a closer evaluation of the NBS tests indicated that there was no significant thermal performance advantage in the use of thermosiphonic systems. There are, however, some definite advantages when parasitic power and system economics are considered. These advantages relative to other NBS-tested configurations are indicated in Tables 2-1 and 2-2 below. The figures of merit presented in these tables are normalized ratios of efficiency (best systems = 1.0) divided by initial system cost. Rankings corresponding to both thermal and net system (parasitic losses included) efficiencies are given. A report giving a full description of the NBS systems tested is nearing completion, along with an assessment of component losses, thermal efficiency, system efficiencies, as well as parasitic power consumption [1].

The major difficulty perceived with thermosiphon systems to date has been the apparent problem of adequate freeze protection, as discussed fully in SERI/RR-35-413 [1]. A major finding of this analysis argues that a high-reliability drain-down capability could resolve this concern while allowing solar users to take advantage of the benefits of these systems. Also, recommendations for future development activity, including sound reliability analyses, high efficiency solenoid valves with high reliability, and different drain-down strategies are discussed.

As a result of this study, a conceptual design evolved for an air thermosiphon system that offers freeze protection, a requirement for thermosiphon systems in much of the United States. The concept uses an integral collector-storage combination as shown in Fig. 2-1. The collection unit serves as a preheater rather than a primary heater. The insulating layer above the water tank is automatically positioned, using a thermostatic metal coupling between the collector plate and the insulation as depicted in Fig. 2-1. The insulating baffle is positioned so that the tank is completely insulated when there is insufficient solar energy to promote energy transport from collection to storage.

Table 2-1. THERMAL EFFICIENCY-BASED RANKING AND RELATIVE FIGURE OF MERIT FOR THE SOLAR WATER HEATING SYSTEM CONFIGURATIONS TESTED BY NBS

		Normalized Figure of Merit	
Ranking	System Configuration	Collector Cost $7.50/ft^2	Collector Cost $15/ft^2
1	Single Tank, Thermosiphon	1.0	1.0
2	Single Tank, Direct[a]	0.812	0.913
3	Single Tank, Indirect	0.513	0.607
4	Double Tank, Direct	0.428	0.498
5	Double Tank, Indirect	0.341	0.416
6	Double Tank, Air	0.122	0.151

[a]If the fluid from the collector is transferred directly to the storage tank the system is called direct. If a heat exchanger is used to isolate the collector fluid in the collector loop from the storage (i.e., like an antifreeze solution), then the system is called indirect.

Table 2-2. SYSTEM EFFICIENCY-BASED RANKING AND RELATIVE FIGURE OF MERIT FOR THE SOLAR WATER HEATING SYSTEM CONFIGURATIONS TESTED BY NBS

		Normalized Figure of Merit	
Ranking	System Configuration	Collector Cost $7.50/ft^2	Collector Cost $15/ft^2
1	Single Tank, Thermosiphon	1.0	1.0
2	Single Tank, Direct	0.636	0.715
3	Single Tank, Indirect	0.470	0.555
4	Double Tank, Direct	0.308	0.362[a]
5	Double Tank, Indirect	0.300	0.366
6	Double Tank, Air	0.059	0.073

[a]Note in this one instance that there is a reversal in ranking; however, the Figures of Merit for 4 and 5 are nearly identical.

A computer performance program (using MITAS II) was written to predict the air thermosiphon flow rate and collection efficiency. Results show that the unit would operate at an efficiency of 15% and 25% for nonselective and selective absorbers, respectively. Though the efficiency is low, the unit's estimated cost is sufficiently low that the specific cost (dollars/efficiency) looks attractive when compared to some other solar hot water heaters. The normalized figure of merit corresponding to Table 2-2 is 0.459 based on $7.50/ft^2 and 0.691 based on $15/ft^2 collector cost, respectively. Its potential high reliability could further enhance its overall attractiveness. A patent application for this concept was filed through DOE with the Office of Patent Counsel on 29 March 1979. Further analysis and development work will be carried out to determine whether the concept bears continued development.

2.2 SOLAR PONDS

As part of the continuing need to evolve and identify new, promising concepts, SERI has undertaken a study of solar ponds that may have potential benefits for both district and industrial process heat applications.

Solar ponds are conveniently classified as either salty (i.e., stratified) or saltless. The salty ponds contain a salinity gradient (which results in a density gradient) to reduce the heat loss by preventing convection within the water storage medium. Saltless ponds reduce heat loss by covering the pond's surface with transparent insulation. In some cases, losses may be further reduced by additional night insulation. These are different from shallow solar ponds (developed by Lawrence Livermore Laboratory), which are water bag collectors with separate thermal storage. Water is pumped into the bags every morning and transferred to storage in the evening. The saltless ponds considered at SERI are deep ponds that combine the elements of storage and collection, thus avoiding the cost of elaborate plumbing and separate storage structure. They have high potential and low-cost, low-temperature, collector-storage systems.

Solar pond research at SERI has addressed the following areas:

- numerical modeling of stratified salty ponds;
- simplified analytical modeling of stratified salty and saltless ponds;
- salt availability;
- experimental program; and
- economics.

A brief summary of results in each of the areas is described below.

2.2.1 Numerical Modeling of Stratified Salty Ponds

In order to investigate salinity-gradient solar pond performance under realistic weather and load conditions, a detailed numerical thermal simulation program was developed. This program (SOLPOND) models the solar energy absorption characteristics of the pond and the heat transfer and thermal storage within the pond and the surrounding earth. Finite element techniques have been used to describe conduction heat transfer through the pond, earth, and edges. Sensitivity studies of thermal performance with respect to geometry, load, and optical transmission have been calculated. This program will be available to the public through the SERI Code Center. Using this program, performance of solar ponds in different locations of the country also has been calculated.

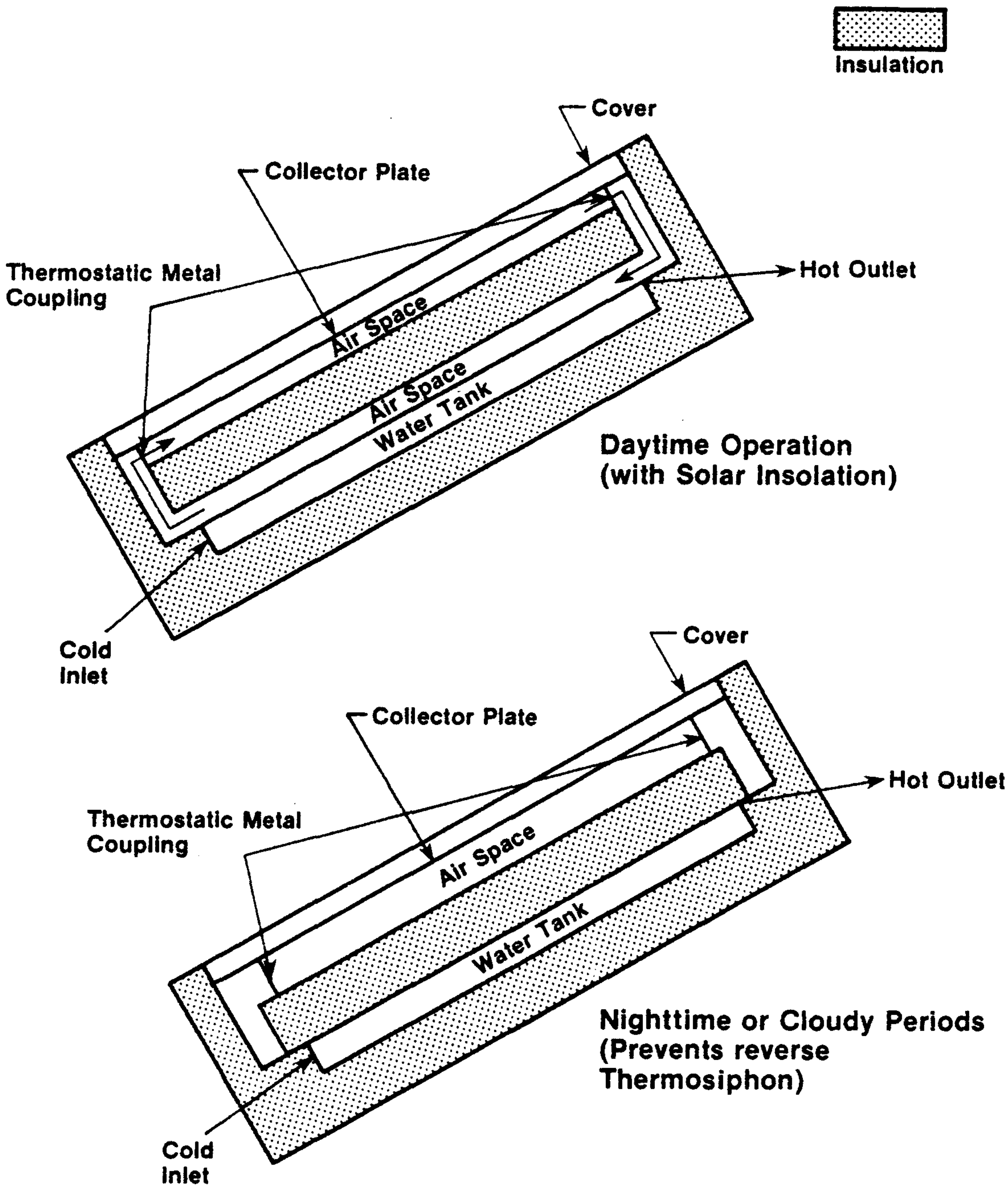


Figure 2-1. Schematic of Thermosiphon Concept

2.2.2 Simplified Analytical Modeling

Simple mathematical models are extremely useful in obtaining an idea of performance of solar ponds. At this stage of solar pond development, when there is scant experimental data, such simple tools may, in fact, be sufficient to predict performance of solar ponds and to size them. A generic mathematical model of solar ponds was developed by considering the system as a lumped parameter thermal network. This model has been used to predict performance of salty and saltless ponds, and to predict maximum and minimum temperatures for different loads at different locations. It has also been used to size solar ponds for residential heating applications in 25 sites across the country. Sizes of solar ponds in the Northeast tend to be two to three times larger than in the Southwest to supply the same residential heating load, because of the widely different climatic conditions in the two parts of the country.

2.2.3 Salt Availability

The cost of salt represents a sizable fraction of the total initial investment for a salty solar pond. A typical pond may require 1/4 to 1/3 ton of salt per square meter of surface area. If the salt is to be bought at $10-20/ton, the cost of salt is 25-50% of the total cost of the pond. Therefore, identification of suitable low cost salts is imperative. The SERI study has concluded that those salts which can be obtained as waste products offer substantial economic advantage for use in solar ponds. The magnesium chloride "bitterns" are available from plants that refine NaCl, and these sites are numerous in different parts of the country. Sodium sulfate has the potential for widespread availability in the next few years as a waste product from flue gas desulfurization (FGD) at coal-fired power plants. A 500 MW_e plant (burning approximately 0.2% sulfur coal) would produce approximately 250 tons of FGD waste per day. Thus, the potential for obtaining free sodium sulfate for use in solar ponds seems to be quite high in areas where power plants utilize the scrubbing process in which sodium sulfate is the waste product.

2.2.4 Experimental Work

An experimental program has been initiated in FY79 to support the analytical work. Small-scale experiments have demonstrated the predicted stability and salinity gradients of the ponds; several other experiments aimed at determining the feasibility of using low cost salts have been initiated.

2.2.5 Saltless Ponds

Since saltless ponds have received little previous research attention, they are presently in the earliest stage of design. The Lawrence Livermore Laboratory's saltless solar ponds have demonstrated some performance success, and significant future design improvements may be realized. SERI investigations have centered on identifying potential areas for design improvements which include:

- reducing plumbing by eliminating separate thermal storage;
- reducing thermal losses with night insulation; and
- providing long-term storage with deep ponds.

2.2.6 Economics

The economics for both salty and saltless ponds are encouraging. Preliminary results indicate the following findings.

- There are potential sources of cheap salt as waste products in chemical processes in the salt industry and in the power industry.
- Modeling and performance prediction indicate that a steady thermal load of 50 W/m^2, at a minimum temperature of 50° C, can be obtained from solar ponds of reasonable depth (approximately 1 m).
- Salty ponds can provide low-temperature solar thermal energy for less than 1¢/kWh_{th} in many locations where salt is inexpensive.
- Saltless ponds have the potential to provide low-temperature solar thermal energy for less than 1.5¢/kWh_{th} in places lacking an inexpensive local salt resource.

Five publications have resulted from the work to date [2,3-6].

2.3 COMPUTATIONAL METHODS CENTER

At the beginning of FY79, SERI was asked to take over the responsibility for the dissemination of F-CHART. It was felt that the best way to do this would be to initiate a Computational Methods Center at SERI, with the objective to catalog and understand all of the major computational methods presently available in solar energy. It also would include the dissemination of selected computer and noncomputer research simulation models and design methods in the public sector. The Computational Methods Center is completely a SERI effort and involves activity within the Commercialization Division, Information Systems Division, Research Division, and Analysis Division. Responsibilities have been delegated and procedures evolved for the dissemination of computer-based codes.

As part of the activity of putting the various computer models onto the SERI/BOR computer, SERI is documenting experiences and problems encountered by those attempting to make the system operational. This information will be used to develop future versions of user manuals and to identify and correct problems within the programs. Close interaction is maintained with the authors of the various programs. The following computer codes have been acquired and are presently operational on the SERI/BOR Computer System: F-CHART, SOLCOST, HUD-RSVP, TRNSYS, NCAT, MITAS, DEROB, DEROB/PASOLE, PASOLE, DOE-2, BLAST, SOLCEL I, and SOLCEL II.

The F-CHART dissemination activity is underway. Activities include the development of user-oriented literature describing the computational method and its capabilities [7]. More than 2,000 copies of this brochure have been distributed. By working with the program authors and the users, SERI has been able to identify needs and define problems that need correcting. SERI has responded to more the 500 technical inquiries regarding problems and the use of F-CHART.

Although SERI has no formal responsibility for SOLCOST, SERI has assisted Martin-Marietta Corporation, Solar Environmental Engineering Corporation (SEEC), and International Business Systems (IBS) in maintaining and disseminating this code. For instance, SERI maintains configuration control of SOLCOST and coordinates development meetings for both Martin-Marietta and SEEC. In late FY79, SERI funded an activity to implement SOLCOST, Version 2.1, on the CYBERNET Network. SERI revised, printed, and disseminated the latest SOLCOST [8] manual. As with F-CHART, SERI has responded to more than 500 user inquiries about SOLCOST.

In FY78, SERI developed a user-oriented brochure on SHAC Analysis Methods [9]. The brochure was developed in response to many inquiries as to the most appropriate analysis and design methods. It lists available analysis and design methods and defines how they can be obtained. During the past six months, SERI has updated that brochure to reflect new information generated by EPRI and others. The updated brochure was first distributed at the 1979 ISES meeting and, since that time, more than 2,000 copies have been distributed.

2.4 COMPUTER CODE DEVELOPMENT

Since SERI has become the national center for the evaluation and dissemination of solar simulation methods and has been given the charter to manage and plan the development of solar analysis methods, evaluation of key solar computer codes was initiated in FY79. This is a first step in establishing a center of expertise and technical credibility. Two important, currently available, state-of-the-art, but relatively new, analysis methods (DOE-2 and DEROB) were chosen as a focus. Both of these codes have been brought on-line during the last quarter of FY79. It should be noted that considerable work on less comprehensive codes has been expended by the SAT team during FY79. These efforts, associated with solar ponds, wind, and photovoltaics, are discussed in more detail in Sections 2.2, 2.6, and 2.9, respectively.

DOE-2 has the capability of analyzing the energy performance of large or small buildings. Developed by LASL and LBL, it has the potential to be a very versatile solar analysis tool. Further, it is a key evaluation tool for the Building Energy Performance Standards (BEPS), and it is also being considered as an arbitration tool for California energy regulations. The solar portions of this code are relatively immature, but active, passive, and combined active and passive systems potentially can be analyzed. Its current passive capability is limited due to the response factor approach used. In FY80, SERI's contribution will be to assist the developers in verifying the solar portions of the code and to provide a responsive, unbiased source of expertise on this method. In FY79, our analyses have uncovered several minor problems, as well as some fundamental limitations to using the code for BEPS evaluation, particularly with respect to passive analysis. Sensitivity studies and comparisons of the solar portions of DOE-2 with the more well-established TRNSYS code have begun and will continue into FY80.

The DEROB computer code is a second area of focus initiated in FY79. This code also is a key element in the BEPS evaluation, particularly for small- and medium-size passive structures. It offers significant user flexibility and is easily amenable to sensitivity studies needed by SERI's Passive Technology Branch (PTB). Work in FY79 has concentrated on debugging the code, gaining user experience, and adding coupled graphics capabilities to the code. Comparative sensitivity studies with the MITAS thermal analyzer have been made and configuration studies are underway with the PTB Branch, which will continue into FY80. These component configuration studies are investigating three-dimensional heat transfer processes in composite thermal walls. Various methods of enhancing conductive heat transfer through a wall are being analyzed. Various wall configurations, including composite structures with high conductivity surfaces as well as imbedded elements normal to the wall surface, are being considered.

2.5 PROCESS HEAT

Several activities initiated in FY70 will continue into FY80, while others have identified fruitful areas of research. The SAT support is now filling a much-needed systems perspective in the national process heat effort. In FY79, numerous studies and analyses were completed and five publications will result by November 1979.

An applications matching study was completed for six cities (Fresno, Calif.; El Paso, Tex.; Brownsville, Tex.; Bismarck, N.D.; and Charleston, S.C.) in which promising IPH systems were identified for application to representative low- and medium-temperature industrial processes [10]. The most cost-effective applications were for low temperature ($<60°$C) cleanups and used parabolic or flat-plate collectors. The polar-mounted fresnel lenses performed very well in all locations for medium temperature applications ($60<T<77°$C).

Six field case studies with local industrial plants were also completed to identify conservation and solar potential and to assess the correctness of assumptions incorporated in applications matching [11]. It was found that traditional practices can often inappropriately rule out a potential solar application. Each application must be investigated separately. As an example, the wet corn milling industry has always been classified as a high temperature application for IPH. Historically, feed drying was done at temperatures of about 700°F due to the availability of low-cost and high-quality natural gas. However, only 200°F temperatures are actually needed; solar systems might economically supply this energy in some cases.

Finally, field trips were made to six operating field engineering test sites to obtain comparative cost and performance data [12]. Annual net operating efficiencies were much lower than originally anticipated (20% and under), and costs in most cases were high. However, this might have been expected in the first round of field engineering tests for IPH. What is more disconcerting, however, is that many of the problems encountered in earlier SHACOB demonstrations were repeated in the first six IPH projects. This points out the need for improved communication of project experience among all contractors.

An in-depth technical, economic, feasibility analysis, including plant site visits, was prepared for six selected industries—fluid milk dairies, bakeries, paint resin manufacturing, wet corn milling, cane sugar refining, and petroleum refining [13]. This analysis defined the best near-term technical matches to the particular process application and will be used to help define other near-market goals and system development requirements.

A standard economic and cost analysis methodology for IPH analysis and project reporting was developed in cooperation with Lawrence Livermore Laboratory [14]. It will form the basis for all future IPH systems studies.

A cooperative network was established among DOE-sponsored researchers to gather and consolidate data on energy use in specific industrial plants. Data to be collected include: heat and electricity use, operating schedules, locations, process temperatures, fluid types, regulatory restrictions, and investment criteria. This data center is now in operation at SERI and will have its first data entries by November 1979.

Finally, four papers to be presented at the opening IPH conference have been prepared [15-18]. These papers discuss solar pond applications to process heat as well as the market, economic and systems studies discussed above.

2.6 WIND ENERGY SYSTEMS STUDIES

Many feel that small wind sytems are nearing commercialization. As a result, it was felt that some initial activity was necessary to begin to understand such systems in the context of the needs of users, researchers, and designers for the various dispersed applications. During the first half of FY79, a survey of existing wind turbine performance models was made. The purpose of this study was to generate a data base, similar to an earlier one developed for SHAC simulation models, to guide future analysis and design method development. The results of this analysis were documented in a separate report [19], and a popularized brochure was developed for the user community [20]. This brochure is quite similar to the SHAC Analysis Method brochure that was first published in 1978, and more than 1,500 copies have been distributed.

A second part of the wind systems studies focused on the effects of wind transients, control systems, and load management on energy capture. The objective was to determine whether such effects could significantly alter performance of wind machines as presently predicted by steady-state models. Variations of more than 20% from the steady-state predictions might be realized. This study consists of five subtasks: Model Assessment, Aerodynamics, Meteorological Data, Subsystems Analysis, and Systems Analysis. These subtasks are defined in more detail in SERI/SP-35-313 [21].

In FY79, the model assessment has been completed, and data on the aerodynamic characteristics of the NASA MOD-OA and UMASS WF-1 wind turbine rotors have been collected. Wind data were obtained from Rocky Flats, and further data on candidate sites for large WECS should be available soon. Furthermore, most of the subsystem specifications for the NASA MOD-OA were obtained. All of these data will be used to benchmark the WINSYS code (described below) currently under development.

The major focus in FY79 has been the development of the WINSYS code and the completion of a data sampling error analysis [22]. The WINSYS code solves the general equation of motion of the turbine generator combination in the wind stream, thus determining the real-time response of the turbine, including the transfer function between wind speed and power output. The wind stream is assumed to be uniform over the rotor, and interaction with the supporting structure is not considered. Thus, the commonly used simplifying assumptions, such as an assumed wind velocity probability distribution and assumed instantaneous-velocity power-output relationships, are obviated by the WINSYS productivity analysis. The coding for WINSYS is basically complete, but the code has not been debugged or tested with realistic data. This real-time simulation program uses weather tapes and machine parameters as inputs. This work will continue in FY80.

A second area of focus looked at using actual wind-time history data with an assumed instantaneous turbine power-velocity relationship. This approach will give an upper estimate of the power attainable from a wind stream if the time record is continuous. Sensitivities have been investigated in predicted energy productivity for different sampling intervals and different power-velocity relationships. There are clear limits to the accuracy of energy estimates for various sample intervals: a sample time of no more than 4% of the data interval is acceptable if 10% error is acceptable. This indicates the need for detailed wind records and high sampling rates for the data. Clearly, the filtering characteristics of the turbine will greatly affect whether extremely small sampling increments will be required. The completion of the turbine simulation effort will answer this question.

2.7 THERMOGRAPHY

Thermography, or infrared photography, is used to illustrate and detect temperature differences in devices or structures. For instance, utilities use thermography to detect the overheating of line capacitors, and ASHRAE energy auditors investigate energy flows in buildings with infrared photography.

Thermography appears to have considerable merit as a solar system diagnostic tool. It can be used not only to assess the relative energy flows in passive structures, but also to identify temperature gradients in solar collectors of any kind. Such temperature gradients with active system collectors often are caused by flow imbalances. These flow imbalances can sometimes lead to damage of the systems and degraded system performance. Such a diagnostic tool can be extremely valuable to utilities, energy auditors, and solar firms in diagnosing whether a collector (or array) is functioning correctly.

In FY79, seven operating solar installations were thermographed, and the utility of this tool was demonstrated. Furthermore, when used correctly, low-cost hand-held units were shown to have sufficient resolution capabilities to detect most commonly occurring problems. In two of the five installations, unknown system problems were revealed by the thermograph results. In one case, an array had been inadvertently shut off; in the other, a thermal mass tank which should have been filled with water was empty. A typical thermograph photograph is shown in Fig. 2-2. A report on this work will be prepared in FY80.

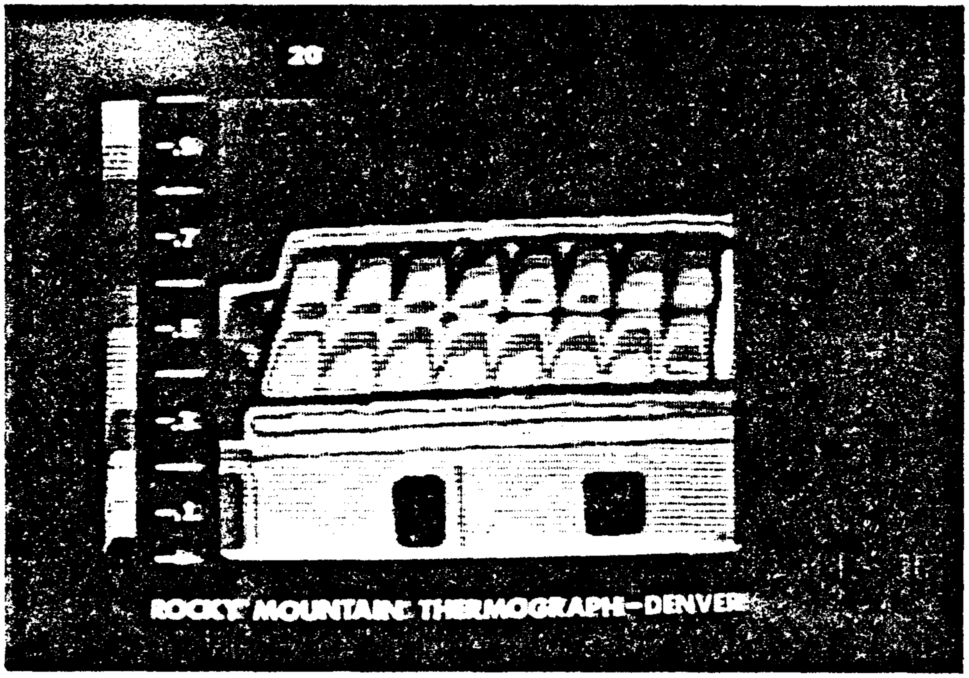
2.8 STANDARD ASSUMPTIONS

Analyses of solar heating or cooling systems require as inputs meteorological data (i.e., temperatures, dew point, insolation, and wind) and well-defined building configurations to determine the load characteristics. In the past, researchers analyzing different systems generally have not modeled identical buildings in identical locations using the same weather data. Since these parameters greatly influence the performance of the system, it is difficult to make meaningful correlations among different systems or from different analysis methods. Furthermore, a common data set and a consistent performance basis are sorely needed in investigating the sensitivity of system operation to various components or the environment (climatic or economic).

To address these needs, a standard set of assumptions has been developed and published in FY79 [23]. This document prescribes a set of locations, meteorological data, and building descriptions for use in solar system analyses and analyses of conventional buildings. It is expected that this document will be updated as better data become available. Furthermore, it will be a model for similar data sets corresponding to the application of other solar technologies, such as photovoltaics, wind, and process heat.

2.9 PHOTOVOLTAIC ANALYSIS METHODS

Remote applications of photovoltaic systems are undergoing or near commercialization. As part of an analysis of availability of simulation and design tools for photovoltaics, a



Note: This picture, taken (in color) of the collectors on Solar House I at Colorado State University, shows approximately only a 10° C variation of the collector surface temperature. Light (dark) areas correspond to the hotter (cooler) regions of the collectors. The original color pictures provide a more dramatic illustration of the temperature variations through gradation in colors.

Figure 2-2. A Typical Thermographic Print of An Active Solar Collector

study was undertaken to identify current photovoltaic simulation and analysis methods. The purposes of this study were to:

- establish a base of information regarding existing photovoltaic simulation/design capability;
- make this information available to the user community; and
- assist in identifying future tool development needs/directions.

The results of the photovoltaic model review have been documented [24] in a popularized brochure developed as part of a series on design methods (others are Wind and SHAC) and distributed at the 1979 ISES meetings. More than 1,500 copies of this brochure have been distributed. The document is expected to be updated to reflect the latest information in photovoltaics.

In addition to bringing the SOLCEL codes on-line, a simplified photovoltaics sizing code was developed by SAT and the CSB in FY79. A given load profile is used as input, from which the code calculates estimates for the required size of the array, storage batteries, and inverters; it is written for the HP9845 programmable calculator. This code will be used when the level of information available is limited and when a quick, first-order approximation is warranted.

2.10 SUPPORTING ANALYSIS

As part of SERI's Systems Analysis Branch, the SAT team provides technical support for SERI in the area of analysis. The breadth of expertise and a systems perspective make this support extremely valuable. The systems perspective allows the specific research and analysis to be integrated with broader needs associated with applications, demonstrations, and, finally, commercialization. The SAT team has provided technical resources and supporting analysis to numerous internal SERI groups, including the Passive and Resource Assessment Branches, as well as to DOE.

For example, the SAT team has studied the impact of weather data errors on the solar simulation methods F-CHART and SOLCOST. SAT expertise with computer codes such as DEROB, SUNCAT, and TRNSYS is supporting SERI's Passive Branch in its configuration sensitivity studies. Also, the SAT team assisted in the analysis and technical support for the Small Power System Simulation Programs and in the design of small community systems for the International Program. Furthermore, technical support to DOE requires short-term analysis. Examples include the model audit analysis for the Residential Conservation Service (RCS) and the evaluation tool analysis for the Building Energy Performance Standards (BEPS).

2.11 CONTROLS

SERI will become the lead center (currently at Lawrence Berkeley) for the Solar Controls Program beginning in FY80. During FY79, SERI reviewed previous work on the Controls Program as part of our program management effort. The management effort has been directed to lead into our new responsibilities in FY80. A particular concern was the lack of comprehensive organization among previous control program contracts and the identified current problems within existing solar installations.

In FY79 reliability and maintenance were identified as potential areas in which controls development can make a major contribution. Also, the reduction of parasitic power was cited as a significant design direction for future control hardware development. Finally, energy conservation through load matching (i.e., modifying the user energy demand to match more closely available solar energy) appears to be a potentially attractive area in which controls may be used to reduce auxiliary energy conservation.

These results indicate that major shifts should occur in future funding directions. However, several areas of previously heavy support will continue as major elements in the Controls Program, including evaluating new or advanced control configurations and developing off-peak rate load management controllers. The major initial effort by the SAT team in FY80 will be to formalize and implement a comprehensive national solar controls plan.

SECTION 3.0

SYSTEMS TEST

The Systems Test area of the SAT program is concerned with the conduct/coordination of tests to verify and optimize system economic and engineering performance, as well as to generate data to be used in the validation process. Most of the testing work is being performed by external organizations, such as Colorado State University, University of Pennsylvania, University of Texas, National Bureau of Standards, and the U.S. Housing and Urban Development (HUD) demonstration program.

SERI activity in the Systems Test area was limited in FY79 to the development of the Integrated Test and Validation Plan, which is discussed in Section 4.0. Funding to implement this plan was not available in FY79.

DOE currently is supporting a number of data-gathering activities for solar heating and cooling. A major element of the program is the effort associated with the HUD demonstration program, in which some 100 buildings are extensively instrumented and continuously monitored. The data then are analyzed and stored in a central location, from which they are periodically published and disseminated.

Since late July 1979, the SAT team has been assisting DOE in assessing the present data program to determine whether modifications are warranted. The assessment addresses the following five issues.

- Why do systems testing? What are the data for?
- What kind of data is necessary? What kind of data is desirable?
- How are those data obtained? At what cost?
- How should the data be reported and disseminated?
- What feedback mechanism is necessary to ensure program effectiveness?

A draft data requirements plan is expected in early FY80.

SERI

SECTION 4.0

SYSTEMS VALIDATION

A major concern in the solar community is whether solar analysis and design methods have been demonstrated to give valid results in realistic applications. During FY79, initial development of a validation methodology was undertaken by the SAT program. Two different approaches were developed: the first by Science Applications Inc. (SAI) and the second by SERI. These two approaches are described briefly below.

4.1 SAI APPROACH

In support of SERI, SAI was assigned to develop and implement a validation methodology for solar water heaters. After the SERI review, the SAI work was determined to have certain merits but was considered to be too costly and inappropriate in scope for nonresearch users of design codes. The proposed SAI methodology compares a reference research code to constrained experimental data,* compares the design code to the research codes, performs a sensitivity analysis of the design code to input parameter variations, and, finally, compares the design code to field-test data. However, even if the cost of the supporting data were not prohibitive, the SAI proposed method might lead to results that are statistically meaningless, because the uncertainty in the measurements required for the detail of data requested may be as large as, or exceed, the uncertainty in the parameters themselves. A simpler global approach that would rely on simple, readily measured data appeared necessary. Such an approach was developed at SERI.

4.2 SERI APPROACH

The SERI methodology takes great care in developing simple but statistically valid samples and in measuring variables obtainable with reasonable certainty and having meaning to the typical solar user (e.g., the amount of energy used with and without solar technology). These measurements are compared with computed predictions and statistical estimates for the expected uncertainties associated with simulations as compared to reality. The experimental results would be equally applicable to all codes which simulate the particular application being tested. However, the results are expected to have the most immediate applicability to design codes. The rationale for the methodology is discussed in detail by Cohen and Morrison [25,26]. A pilot study was devised and is proposed for FY80 if funding can be made available.

Very briefly, the proposed SERI pilot study would identify the population of SDHW systems in a region, and a group of systems would be selected according to statistical sampling theory. The sample would be instrumented as inexpensively as possible to determine a few integrated performance values. Design code predictions would be compared with measured performance. Correlated experimental and analytical results would pinpoint problems in the experiment design and confirm statistical parameters required for the larger experiment. In addition, results would provide initial guidance for

*"Constrained" refers to the fact that the experiment is probably under idealized conditions and is not necessarily representative of field experience.

improving analysis methods and refining the assumptions used in these methods. Correlated experimental and analytical results would pinpoint problems in the experiment design and confirm statistical parameters required for the larger experiment.

SECTION 5.0

TECHNICAL AND MANAGEMENT SUPPORT

Because the SAT program is relatively new and involved transfer of management from Sandia Laboratories and DOE/Washington to SERI, considerable effort has been expended on management functions, such as development of program plans, a management plan, and activities related to managing external research organizations under DOE or SERI contract. These activities are described in the sections that follow.

5.1 SAT PROGRAM PLAN

A major activity undertaken during this reporting period has been the development of a national plan for the SAT program. That plan has been completed in draft form and is currently being reviewed [27]. The plan describes the objectives of the SAT program; the major program elements (Systems Analysis, Systems Test, Systems Validation, and Systems Control); the interaction and relationships among those elements; their specific near-term and far-term objectives; the status of the various elements regarding meeting those objectives; and FY79 activities/tasks being undertaken in each area. The SAT Program Plan has not been approved formally by DOE at this time.

5.2 INTEGRATED TEST AND VALIDATION PLAN

The national program in heating and cooling includes the development of many advanced components and subsystems. To coordinate the testing and utilization of these components and subsystems, an integrated test plan was developed. The plan also addresses model validation. The test plan objective is to identify whether all the proper systems are being tested, to define data needs, and to develop an approach to testing systems. It is also meant to identify additional needs for new test facilities and to schedule future system testing within the R&D branch in DOE.

The approach taken in developing this plan was first to identify the generic systems within the categories of domestic hot water, space heating, space cooling, and agricultural and industrial process heat. Second, an attempt was made to identify whether these systems have been or are being tested within the context of the U.S. solar energy program. Also, if they are being tested, are they being instrumented and are test data being collected that would be useful in the validation process? The report addresses the present test facility capabilities in both government and private sectors, the components and subsystems that are emerging from the R&D program, and the scheduled availability. A preliminary draft of the plan was issued in October 1978. A final draft of the plan is scheduled for release in November 1979 [28].

5.3 MANAGEMENT PLAN

A Management Plan for the Systems Analysis and Testing (SAT) program addressing the role of the SAT program within the overall SERI organization has been developed [29]. The plan describes the SAT program, reporting relationships, the organization of the internal SERI tasks, and research performed by outside organizations. It will act as an overall guide for the management of the SAT program.

5.4 BUILDING ENERGY PERFORMANCE STANDARDS (BEPS)

The BEPS program is a federally mandated program which requires that new commercial and residential buildings meet certain energy-use guidelines. Solar energy is an approved option that can help prospective building owners reduce energy consumption and meet these guidelines. Interim BEPS standards have been in effect since September 1979 and the final regulations are expected in February 1980. Since June 1979, SERI has managed, at DOE's request, the effort in defining the appropriate solar analysis methods for the BEPS evaluation. These methods must be consistent with the methods used for the "conservation only" evaluation.* Furthermore, the methods should give the most accurate solar assessment possible and should be accessible to the solar user.

In FY79 the SAT team performed the initial BEPS management role, with SAI performing the technical coordination role in the solar support documentation for the evaluation procedures. SAT personnel reviewed proposed methods and provided both backup analysis on method development and inputs for the final BEPS support documentation.

5.5 RESIDENTIAL CONSERVATION SERVICE (RCS)

The objectives of RCS for all existing residential housing units are similar to those for new building units in the BEPS program. However, instead of mandating standards in existing housing, a service in the form of an energy audit, to demonstrate to the building owner how to decrease his energy use, will be offered. Like BEPS, this program is federally mandated by law. Also, like BEPS, the bulk of the actions recommended to consumers will be conservation measures, but the auditor must be prepared to recommend appropriate solar measures and to assess their impacts upon the users' energy use and cash flow.

The SERI Special Projects Office has been asked to assume the management lead for the solar components of RCS; SAT personnel have provided technical support since project inception in August 1979. The SAT team developed a single, integrated solar and conservation model audit, along with a detailed rationale for using the analysis procedures in implementing the audit.

5.6 NATIONAL ANALYSIS AND DESIGN METHODS PLAN

A national plan for the development of solar analysis and design methods is being formulated [30]. Its objective is to provide a context and an organizational structure in which the essential analysis and design method development needs for solar heating and cooling can best be defined and met. A program consisting of four interrelated projects is presented. The plan addresses active, passive, and combined active and passive (or hybrid) systems, but the approach is equally applicable to all solar technologies.

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*Many current building performance analysis methods do not explicitly consider solar applications. However, most compliance measures for BEPS in the near future are expected to be "conservation only" (insulation, weather stripping, efficient furnaces, etc.).

This plan describes a process to (1) identify solar system predictive tool needs, (2) develop these predictive tools, (3) develop and implement a proven validation process, and (4) disseminate the appropriate tools to the user community. The user community includes solar designers, installers, analysts, researchers, energy auditors, consumers, energy consultants, and others. Predictive tools include both computer and noncomputer-based analysis methods. Noncomputer-based methods are especially appropriate for design use. Near-term objectives are aimed at developing and validating methods needed by the BEPS and RCS programs.

5.7 PROGRAM MANAGEMENT ACTIVITIES

Technical management of the DOE contracts in the Systems Analysis and Testing area was transferred from Sandia Laboratories (Albuquerque) to SERI at the end of FY78. During the first half of FY79, SERI reviewed the work of all the systems contractors and made site visits to all but one. Several meetings were held to ensure that each contractor was working according to the SAT Program Plan developed at SERI.

In coordination with DOE and the contractors, SERI has prepared a Statement of Work for several DOE renewal contracts for FY79.

• Research Development in Solar Energy Applications (Colorado State University)	$600K
• Performance Analysis and Optimization of the University of Pennsylvania Retrojected Solar Heated Philadelphia Row House (University of Pennsylvania)	$19K
• Simulation and Design of Solar Thermal Processes (University of Wisconsin)	$300K

Procurement request packages were prepared for these contracts and sent to the DOE Chicago Operations Office.

Several subcontracts were let and are being managed by SERI in FY79 as part of the SAT Program. Two of them involve follow-up work from previous DOE contracts (SAI and CSU), and the others are new efforts. SERI has initiated a Basic Ordering Agreement with Science Applications, Inc., to perform systems analysis work. There are four tasks underway in this contract:

- technical support and preparation of reports in systems analysis;
- advanced solar-assisted heat pump studies;
- technical support to the Building Energy Performance Standards Program; and
- technical support to the Residential Conservation Service Program.

The SAI subcontract had several accomplishments during FY79. Support was given to the BEPS program in the development of a Technical Support Document and modified design tools for solar heating and cooling. A final version of a report on solar-assisted heat pumps was produced which indicated that they are not economically viable under any conditions. Support was given to the RCS program in the development of a model audit procedure and auditor training guidelines. An analysis of solar measures of the RCS program was performed for the final ruling. In addition, several documents were prepared that describe building thermal loads for use in a standardized system analysis methodology. A report on this project to validate the TBY data was produced and disseminated.

The SERI subcontracts currently underway in the SAT program are the following.

• Studies and Analyses of Advanced Systems for Solar Applications (Science Applications, Inc., Basic Ordering Agreement)	$750K
• System Checkout and Control Handbooks for Solar Domestic Hot Water Systems (Solar Environmental Engineering Co., Inc.)	$62K
• Solar Supplement to Laundry Drying (Colorado State University)	$19K
• Support to SSEA and IEA Task 6 Workshops (Atlas, Inc.)	$28K
• Development of a Solar Design Code Incorporating Both Active and Passive Systems (Booz, Allen, & Hamilton, Inc.)	$115K
• Review and Development of Solar Handbooks: Collector Performance and Domestic Hot Water (ASHRAE)	$85K

During the reporting period, SERI conducted two unsolicited evaluations which reviewed 12 formal proposals and 11 preliminary proposals. Four of the formal proposals were recommended for funding—one by DOE, the others by SERI. Two formal proposals were requested as a result of the preliminary proposal evaluation.

The other subcontracts were placed near the end of the fiscal year. No significant accomplishments have resulted from them as yet.

5.8 SOLCOST/F-CHART PLAN

Early in the fiscal year, an evaluation of SOLCOST and F-CHART identified the following needs:

- provide adequate documentation for both programs and a peer review of the SOLCOST methodology;
- conduct an error analysis for both programs, which should be made part of the program output;
- modify both programs to include parasitic power losses;
- oversee the weather data base used in both programs to ensure commonality (SERI Energy Resource Assessment Branch);
- modify both programs, if possible, to reflect currently marketed solar systems;
- standardize user manuals as much as possible;
- validate both programs; and
- coordinate development of both programs to maximize effectiveness.

These activities will be undertaken as time and funds permit.

SECTION 6.0

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Document Control Page	1. SERI Report No. SERI/PR-35-419	2. NTIS Accession No.	3. Recipient's Accession No.

4. Title and Subtitle Systems Analysis and Testing (SAT) Program: Annual Progress Report, October 1, 1978 - September 30, 1979	5. Publication Date November 1979
	6.
7. Author(s) Murphy, L. M.	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Solar Energy Research Institute/DOE 1617 Cole Blvd. Golden, CO 80401	10. Project/Task/Work Unit No. Task #3525
	11. Contract (C) or Grant (G) No. (C) (G)
12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered Progress Report Oct. 1, 1978 - Sept. 30, 1979
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report describes in detail activities and results obtained during FY79 by the SAT team in the Systems Analysis Branch. Effort focused on systems analysis, system testing, system validation and management support to DOE. Results include:
(1) Development of analysis methods for, and evaluation of, generic water heat systems, stratified solar ponds, process heat systems, wind systems, photovoltaic systems, passive solar concepts, and active heating and cooling systems.
(2) Evaluation and planning on a national scope for solar controls, system testing, systems validation, and the development of new analysis methods for solar systems.
(3) The establishment of a national solar code center at SERI and the implementation of the national scope management and planning responsibilities for the systems analysis program under Conservational Solar Applications, R&D Branch, DOE. Also as results of FY79 efforts, a number of innovative concepts, such as a novel air-thermosiphon system and a procedure to apply thermography as a diagnostic tool for solar systems, have been devised. Finally, 26 publications, referenced in this report, have resulted.

17. Document Analysis

a. Descriptors Systems Analysis ; Solar Domestic Hot Water Systems ; Solar Ponds ; Statistical Models ; Mathematical Models ; Industrial Process Heat ; Wind Energy Conversion Systems ; Management ; Thermography ; Standards ; Photovoltaics Cells ; Control Systems

b. Identifiers/Open-Ended Terms

Solar Energy REsearch Institute. Computational Methods Center.

c. UC Categories

UC-59, 60, 63

18. Availability Statement NTIS, U. S. Dept. of Commerce 5285 Port Royal Road Springfield, VA 22161	19. No. of Pages 35
	20. Price $4.50

Form No. 8200-13 (6-79)