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ACTIVE HEATING/COOLING SYSTEMS SUPPORT

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ABSTRACT

Support to the active heating and cooling program involves many varied activities including analysis, testing, validation, engineering handbook development/dissemination and management. This paper addresses work performed by the Solar Energy Research Institute (SERI), its subcontractors, and other laboratories/institutions in the area of systems support since the last review meeting, held in September 1978.

BACKGROUND

In late FY78, the Solar Energy Research Institute (SERI) accepted the responsibility for the development and management of the Systems Analysis and Tests (SAT) Program, a major program element of the National Solar Heating and Cooling Program within the Systems Development Division, Office of Conservation and Solar Applications, U.S. Department of Energy (DOE). Reference 1 discusses the early work performed in this program, and Refs. 2 and 3 summarizes FY79 activities.

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 behaviors; 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 tools to the user community.

SUMMARY

Major accomplishments since the last conference include development of a set of standard assumptions to be used in systems analyses to establish consistency in such work; an objective analysis of solar hot water systems where both net thermal performance and economics are considered; development of cost/performance goals for heat pumps and solar cooling systems; development of handbooks for domestic hot water systems, including controls; analyses which point to the near-term viability of solar ponds; and the development of an integrated active/passive solar system analysis capability.

These projects, and others funded as part of the SAT program, are discussed in the bulk of this paper. Both in-house effects and subcontracted work will be discussed. Work performed in support of the heating/cooling program by the National Bureau of Standards, Science Applications Inc., University of Wisconsin, Colorado State University, and Vitro Labs will not be discussed here as they have been reported elsewhere in this document. Also, controls work, which is in the process of being consolidated with the SAT program, is discussed as a separate element within this document.

TECHNICAL ACCOMPLISHMENTS

This section addresses the technical and programmatic accomplishments achieved by the various organizations involved over the time period covered.

Technical/Management Support

Because of SERI's lead role responsibility in the support area, a major concern is the coordination and implementation of the overall support program elements. Programmatic activities accomplished since the last review meeting include the development of a draft SAT Program Plan which is currently being reviewed by DOE, and a Management Plan (Ref. 4).

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 (Ref. 5). 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 Systems Development Division 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.

SERI has also provided technical support to DOE in the areas of Building Energy Performance Standards (BEPS) by reviewing technical documents and providing backup analyses; Residential Conservation Service (RCS) where assistance was
provided to develop the solar portion of the audit procedure; and in the development of an integrated Analysis and Design Methods Plan which will address the development of methods for the analysis of active, passive and confined active/passive (hybrid) systems. This latter plan will be available in draft form in mid-1980.

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. Major analytical studies are presently being performed by SAI, as a subcontract to SERI, on heat pumps and solar cooling systems. This work, which is aimed at defining cost/performance goals, is discussed in a separate paper. Other current activities within the Systems Analysis area are described below.

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

Findings of this study (Ref. 8), based on an intensive literature search to locate side-by-side performance comparisons of thermosyphon 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 thermosyphon 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 Table 1. The figures of merit presented in this table are normalized rates 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.

The major difficulty perceived with thermosyphon systems to date has been the apparent problem of adequate freeze protection, as discussed fully in Ref. 6. 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.

(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 as 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. Five publications have resulted from the recent work (Refs. 7, 8, 9, 10, 11).

(a) 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 heat transfer and thermal storage within the pond and the surrounding earth (Ref. 8, 9). 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 has also been calculated.

(b) 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 (Ref. 7). 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. Because of the widely different climatic conditions in the two parts of 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.

(c) Salt Availability: The cost of salt represents a sizeable 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. 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.
(d) Experimental Work: An experimental program was 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.

(e) 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.

(f) 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 predictions indicate that a steady thermal load of 50 W/m², 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 1.5 kwh/m² 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/m² in locations lacking an inexpensive local salt resource.

(g) District Heating: The concept of district heating on a neighborhood scale is currently being examined as a possible end use of energy supplied by a solar pond. This task includes several phases. First, SOLPOND, the thermal performance simulation code, was checked for accuracy by comparing its predictions with measured data obtained from the Miamisburg, Ohio pond (Ref. 8). This study indicated that SOLPOND is capable of very accurate predictions if the critical properties and parameters are known. Satisfied that the program is adequate for the district heating study, work has now begun on the sizing ponds for a variety of district sizes in a number of locations. Once complete, this information will be combined with specifications for the balance of the components necessary for district heating, such as pumps, piping, and heat exchangers; and to formulate an overall system design. System thermal and economic performance will then be studied, and the feasibility of ponds for district heating assessed.

(3) Standard Assumptions Document: Analyses of solar heating or cooling systems require as inputs meteorological data (i.e., temperatures, dew point, insulation, 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 inputs, assumptions, analytical methods, and a reporting format for use in residential and commercial solar system analyses have been developed and published (Ref. 15). Significant inputs were developed by Science Applications Inc., and TPI as part of subcontracted efforts to SERI. These standards should facilitate the comparison of results of analyses being performed by different investigators. By the common use of load data, meteorological data, economic parameters and reporting format, researchers examining, for example, two types of collectors may more easily compare their results. Only parameters not directly related to the energy system of a building are specified (with the exception of passive systems, in which the building is integral to the energy system) so that no biases are introduced into the analysis. In addition, a variety of climates are characterized that are typical of those found in the United States. Evaluating system performance in each of the locations can yield valuable information about the most promising location for immediate market penetration.

This document will require periodic updating to provide analysts with the most appropriate inputs and to assure that the results of systems analyses are based on the most meaningful information. Updating is especially important for rapidly changing information such as economic parameters. Subsequent revisions of this report will be available from SERI.

(4) Heat Pump Demonstration Analyses: The object of the heat pump demonstration analyses tank, a SERI FY78 activity, is to assess the performance of operating heat pump systems (both conventional and solar assisted) in the field. That assessment will include engineering and economic performance, including operation and maintenance aspects. Results of the assessment will be compared with the analytical studies being performed by SAI. The final result is expected to be a report which documents the status of heat pump performance, the prospects of solar-assisted heat pumps, R&D requirements for future focus, and cost/performance goals to guide and measure development efforts. Work to date has been the development of the work statement for the field assessment. Analytical results of the heat pump comparative results are discussed in the presentation by SAI, which is located elsewhere in this document.

(5) Analysis/Design Method User Requirements: To properly focus future developmental efforts of analysis/design methods, a study was initiated to analyze and define user requirements/needs/abilities. The object of the study is to define the decision-making process in the residential building industry and define the needs/requirements for solar design and analysis tools. Large, medium and small builders will be studied and characterized. Their requirements for analysis/design methods will be defined in terms of content, complexity, ease of use, etc. The results of the study being performed by Booz, Allen, and Hamilton, will be used to guide future development of analyses/design methods.

(6) Integration of Active and Passive Analysis Capability: Until recently analytical capability for active and passive solar systems existed as separate entities. Comparative analyses of active and passive proved difficult, if not impossible. Perceived needs of the Residential Conservation Service (RCS) program dictated the development of a singular analysis method which would be capable of performing consistent analyses of active, passive and conservation techniques. As a
result, a contract was given to Booz, Allen, & Hamilton to integrate the Solar Load Ratio (SLR) method (Ref. 13), a simplified passive systems analysis procedure, into the Residential Viability Program (RSP) (Ref. 14) analysis method. RSP is based on the F-Chart method of analysis for active systems. The resultant program of this activity will be called PACE (Passive/Active/Conservation Evolution) Program. A working version of the program has been developed, implementing up to five passive systems within a residence. An optimization sizing routine for the passive systems is being developed along with revised output formats. The latest version of F-Chart will be incorporated into this method. The program and documentation, including a User and Programmer Manual, will be delivered by July 1980.

(7) Handbooks: An important activity of the system support area is the development of appropriate engineering-oriented handbooks. Two efforts are currently underway in this area: the development of handbooks by ASHRAE on collector performance and solar domestic hot water; and the development of a solar domestic hot water inspection and performance evaluation handbook by Solar Environmental Engineering Company (SEEC). SEEC is also developing a handbook for controllers used in solar domestic hot water systems. That activity is described in the paper on controls which is located elsewhere in this document.

(a) Inspection and Performance Evaluation Handbook: The Inspection and Performance Evaluation Handbook is an outgrowth of an earlier study which showed that many systems in the field were not performing up to their potential and the users were unaware of this lack of performance. The objective of this handbook is to provide a system startup and service procedures which may be followed by trained technicians so that system performance may be quickly estimated in the ± 10% confidence level.

Procedures which should be followed upon the completion of any installation or during a service call are described in the handbook. Some test equipment not normally used by service personnel is required. The cost of the equipment is relatively small, as is the time required to completely check the system. The extra expense and effort should be rewarded by better system performance, greater system reliability and a more satisfied solar customer.

Sight generic domestic hot water systems are covered in this handbook. The handbook contains three major parts. Each part provides a different starting point for troubleshooting. The proper starting point depends upon the service person's knowledge of solar principles and his familiarity with the particular system being inspected.

Three appendices follow the text. Appendix A is written for the owner or prospective owner of a solar domestic hot water system who has little experience in the field. Simple procedures using inexpensive instruments are described which will allow the owner to determine whether or not his system is operating as it should, although not necessarily at its maximum efficiency. Test equipment that the solar service person should use for thorough system performance evaluations is listed in the second appendix. Recommended taps, plugs, and other hardware which expedite the task of system performance evaluation are described in the third appendix. Installation of this testing equipment should be considered by the designer so that service is easier. In this way, the life cycle cost of the system, including maintenance and repair, may be minimized.

(b) ASHRAE Handbooks: The intent of this effort is to develop two ASHRAE handbooks: a Solar Domestic Hot Water Handbook and a Domestic Hot Water Load Handbook. The DHW handbook is intended to cover all phases of design, installation, operation, and maintenance of solar hot water systems. A review of existing material is included in the contract to avoid duplication of effort.

The second handbook will cover the uses of the information determined from collector tests under ASHRAE standard 93.77. It will cover the prediction of collector performance under various conditions and will give information to aid the specification and design of collectors for various applications.

The contract also covers an ASHRAE review of the Passive Solar Design Handbook (Ref. 13).

(9) 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, which 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.

SERI conducted a thermographic analysis of large solar collector arrays with expensive as well as low cost, hand-held units in Colorado and New Mexico at sites chosen from the National Solar Data Network, plus other instrumented locations. The systems examined included liquid and air flat-plate collectors, both selective and non-selective absorbing surfaces; evacuated tubes; passive houses; and compound parabolic collectors. The system sizes ranged from single family dwelling heating systems to the absorption cooling system on the Base Exchange at Kirtland AFB, which has 930 square meters of collectors. Plumbing configurations were series, parallel, and various combinations. The entire laboratory at Colorado State University was analyzed with its many varied systems and collector types.

The results of the thermographic analysis of the various collector systems were extremely interesting and valuable. Most systems showed temperature distributions which indicated balanced flow patterns both with the thermographs and with the hand-held unit. Subtle differences existed, but these differences were minor. In three significant cases, blocked or broken collector arrays were discovered. One situation was caused by an air blockage within a series-parallel combination of collectors. Thermographic analysis allowed the clearing of the blocked cluster by direct observation of the flow pattern as it was reestablished. Another system was discovered out of action due to a design problem with a drain-down valve. This was detected from a great distance on a very large collector system. The third case was one of a very large array system with a few broken glazings which were noted when examined from a utility-type bucket truck. All these discoveries had gone previously undetected and could be used to illustrate some of the practical applications of thermography as an analysis or operation and maintenance technique. Furthermore, when used correctly, low-cost hand-held units were
shown to have sufficient resolution capabilities to detect most commonly occurring problems.

A report on this work is in preparation (Ref. 15) and a paper has been accepted for presentation at the 1980 ASME Conference.

(9) Computer Code Development/Dissemination: Since SERI is rapidly becoming the national center for the evaluation and dissemination of solar simulation 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 in solar simulation methods. 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 online during the last quarter of FY79. DEROB is a passive code and will not be discussed here.

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 Buildings Energy Performance Standards (BEPS) Program, 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. In FY79, analyses uncovered several minor problems, as well as some fundamental limitations to using the code for BEPS evaluation, particularly with respect to passive analysis. A paper on the capabilities of the component based simulator (CBS) solar portion of the program was presented at the SSEA Conference in San Diego in January 1980 (Ref. 16). 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. Sensitivity studies and comparisons of the solar portions of DOE-2 with the more well-established TRNSYS code have begun and will continue.

At the beginning of FY79 SERI was asked to take over the responsibility for the dissemination of F-Chart. Activities included the development of user-oriented literature describing the computational method and its capabilities (Ref. 17). More than 2000 copies of this brochure have been distributed. By working with the program authors and users, SERI has been able to identify needs and define problems that need correcting. SERI has responded to more than 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 (SEE), and International Business Systems (IBS) in maintaining and disseminating this code. For example, SERI maintains configuration control of SOLCOST and coordinates development meetings for both Martin-Marietta and SEE. 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 manual (Ref. 18). As with F-Chart, SERI has responded to more than 500 user inquiries about SOLCOST.

In FY78, SERI developed a user-oriented brochure on solar heating and cooling analysis methods (Ref. 19). 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 eighteen months, SERI has updated that brochure to reflect new information generated by EPRI and others. More than 15,000 copies have been distributed to the public.

(10) SSEA Conference and Working Group Meetings: The Second Systems Simulation and Economic Analysis (SSEA) Conference was planned by SERI and held January 23-25, 1980 in San Diego, California. More than 175 individuals participated and 75 technical and economic presentations were given during the 2-1/2 day meeting. Photovoltaics, wind, process heat, and thermal electric as well as solar heating and cooling systems were discussed. DOE's participation encouraged the direct and immediate assistance to industries and speakers were asked to address how their work met those needs. The meeting proved quite useful and successful in providing an open format in which the latest technical developments in solar systems analysis were subject to peer review and criticism. A number of issues were raised and discussed at the conference including validation, control strategies, and the unavailability of hybrid analysis methods. The papers along with these and other issues are discussed in detail in the proceedings which will be available in May of 1980.

In addition to the SSEA Conference, the SSEA Working Group met for two days each in May and November 1979. The May meeting addressed simulation model development, validation, and system testing. The November meeting focused on model issues as related to the Building Energy Performance Standards (BEPS) Program and, the Residential Conservation Service (RCS) Program; and the overall subject of validation, including status and methodologies.

Systems Test

Another major element of the SAT program is system testing, which has as an objective the coordination/conduct of system-level tests to evaluate, verify and optimize system economics and performance behavior; and to develop data to use in the validation process. Major programs are underway in the system testing area at Colorado State University, National Bureau of Standards, and Vitro Labs. These programs are discussed in other parts of this document. Other test activities are discussed below:

(1) University of Texas: Funds were provided to the University of Texas at Austin to assist in instrumenting and monitoring performance of a solar heating/cooling demonstration on an apartment building. The system consists of an array of 1280 square feet of Northrup concentrating tracking collectors, a 5000-gallon hot water storage vessel, a 500-gallon chilled water storage vessel, a 25-ton Arkla Industries absorption chiller, and a two-pipe hydraulic air conditioning system. The solar air conditioning equipment is installed in parallel with the existing conventional electric heating and cooling system, and the solar domestic water heating serves as preheat to the existing electric water heaters. The system was instrumented for monitoring with temperature, flow rate, electrical power, and meteorological sensors. It became operational in the summer of 1979.

Data taken in July/August 1979 indicate that 11.2% of the cooling load was met by solar. The reasons for these disappointingly low values are several. The concentrating solar collectors did not perform as well as represented by the manufacturer. In general, the measured collector efficiencies were approximately 60% of the manufacturer's suggested performance curves. This is in part due to a bank of collectors not performing as well as an accurately tracked single collector, which was the basis for the manufacturer's performance data. Also the collector performance is degraded for in-plane
but off-normal radiation. It was also found from tests of a single collector in the University of Texas laboratory that the measured performance of a single collector fell approximately 30% below the manufacturer's recommended performance curve. Another factor influencing the low solar cooling fraction was that the thermostat (sensor in hot tank) turned the chiller on at too low a temperature. This caused excessive cycling of the chiller, which resulted in a poor average chiller C.O.P. Steady-state chiller operation exhibited a C.O.P. very close to the manufacturer's specified performance values.

During this monitoring period the daily average direct-normal radiation was 1165 Btu/ft²-day and the daily average total horizontal radiation was 1357 Btu/ft²-day. The direct-normal radiation is of primary importance since the collectors are concentrating/tracking. While the average direct-normal was 1165 Btu/ft²-day, the maximums on "clear" days were approximately 2500 Btu/ft²-day; in other words, the average direct-normal was a little less than 50% of that available on a "clear" day. In the late summer period of the year this is largely a result of partial (cumulus) cloud cover. The collector efficiency (based on the direct-normal) over this period was 32%, a somewhat lower average collector efficiency than expected.

Approximately six additional weeks of data were taken in the early fall 1979 after the solar domestic hot water was turned on and while solar cooling was still needed. To date, the data has not been reduced and evaluated because of problems with the minicomputer used for data processing. It is expected that this data will be processed and be made available in early 1980.

The evaluation of system performance, which to date is for the cooling season, indicates a lower performance than expected. However, it is felt that system performance in the cooling mode can be improved by better adjustment of the thermostats and controls.

Work in the future will include completion of analysis of data taken during the remainder of the 1979 cooling season (including domestic hot water); and continued data collection/analysis of heating season data. Control strategies will be modified in an attempt to increase system performance.

At the end of summer 1979 the solar system's operation was stopped to (1) allow the examination of its components, (2) recalibrate the instruments, and (3) implement some minor modification. These activities are now complete and the system is operational again.

Reports have been prepared (or are in preparation) on: system and component performance; Philadelphia weather and solar data; data reduction and analysis computer program manual; system construction, operation and maintenance manual; and durability of solar heating system components, and stability of instrumentation. Publications resulting from the work are cited in the reference section (Refs. 20, 21, 22).

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, the SAT program initiated development of a validation methodology and coordinated validation exercises to test the various existing models.

(1) Methodology: In support of SERI, SA! was assigned to develop a validation methodology for solar water heaters (Ref. 23). The proposed SAI methodology compares reference research code to constrained* experimental data, compares the design code to the research codes, and performs a sensitivity analysis of the design code to field-test data. The major concerns with such a methodology are its costs to implementation and its statistical validity 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. The alternative methodology was established in an attempt to develop simple but statistically valid samples, and to measure 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) (Ref. 26). 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.

A proposed pilot study would identify the population of DHW 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 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. Funds, however, are not currently available to implement the proposed study.

(2) Validation Exercises: The SSEA Working Group is coordinating validation exercises. The approach has been to define various test problems in solar heating and cooling and have various individuals/groups attempt to independently predict performance of the system using their respective simulation methods. The group periodically meets to compare and

*Constrained" refers to the fact that the experiment is under idealized conditions and is not necessarily representative of field experience.
resolve differences in their analyses. The exercises provide an opportunity both to study variations in answers when different codes are used, as well as operator variability when the same code is used. To date problems in liquid and in heating systems have been addressed. Most recently the group has begun addressing IPH (Ref. 2) and passive applications.

In addition to the SSEA sponsored validation problems the International Energy Agency (IEA) Task 1 group has addressed validation as part of their activities. The Task 1 group consists of approximately 25 experts in the field of solar system modeling and analysis from approximately 12 different countries, who have met every six months for the last three years. The group was chartered with the task of "establishing a common understanding and basis for the modeling and simulation of solar heating and cooling systems." To this end they have established a series of test problems in solar heating and cooling thermal and economic analysis, performed the analysis with the tools available to each of the participants, met to compare and discuss results, and published draft versions of a final report (Ref. 27). LASL, the University of Wisconsin, and Atlas Corp, has represented the United States the past several years.

Validation work consisted of comparing the TRNSYS and LASL simulation codes with the performance data from the LASL Study Center. In addition, five other codes from Europe and Japan were used. The results of this validation effort was presented at the recent SSEA conference (Ref. 29).

Additional work in an optimization subtask involved comparisons of the F-Chart program to the other IEA simulation codes; performance of an economic sensitivity study development of a graphical optimization technique; and analysis of the economics of selected solar systems in participating IEA countries (Ref. 29).

FUTURE ACTIVITIES

Work the remainder of FY80 is directed toward completion of the activities presented in the previous sections. All topics discussed will result in published reports/papers which will document the accomplishments made in each area.

The various systems analyses being performed on heat pumps and cooling systems will be used to focus and direct the R&D efforts in those areas. Cost/performance goals will be established and used within the technology programs to ensure that the products developed will be viable.

It is expected that the systems support activity will continue to assist DOE in defining cost/performance goals for other areas in the active heating/cooling program, using methodologies developed in the past 18 months; as well as developing validated systems simulation and design methods for the solar community.

ACKNOWLEDGEMENT

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REFERENCES


Table 1: Relative Hot Water System Ranking

<table>
<thead>
<tr>
<th>System</th>
<th>For Collector Cost of $80/m²</th>
<th>For Collector Cost of $82/m²</th>
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