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COLORADO STATE UNIVERSITY PROGRAM FOR
DEVELOPING, TESTING, EVALUATING AND OPTIMIZING
SOLAR HEATING AND COOLING SYSTEMS

PROJECT STATUS REPORT FOR THE MONTHS OF
SEPTEMBER AND OCTOBER 1990

Prepared for the

U.S. Department of Energy
Conservation and Solar Applications
Under Grant DE-FG03-86-SF16306

Submitted by

Solar Energy Applications Laboratory
Colorado State University

November, 1990

MASTER

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November 7, 1990

Report No: SF-16306-24

Report Period: 1 September 1990 to 31 October 1990

PROJECT TITLE:

Developing, Testing, Evaluating and Optimizing Solar Heating and Cooling Systems

GRANT NUMBER: DE-FG03-86-SF16306

GRANTEE NAME: Solar Energy Applications Laboratory
Colorado State University
Fort Collins, Colorado 80523

GRANT PERIOD: 1 June 1986 to 31 March 1990
(Pre-award Costs authorized 1 April through 30 June, 1990)

GENERAL STATUS:

1. Project Objective:

The objective is to develop and test various integrated solar heating, cooling and domestic hot water systems, and to evaluate their performance.

2. Technical Approach:

Systems composed of new, as well as previously tested, components are carefully integrated so that effects of new components on system performance can be clearly delineated. The eight-month program for 1990 is separated into seven tasks. There are tasks for each of the three solar houses, a project to build and test several generic solar water heaters, a project that will evaluate advanced solar domestic hot water components and concepts and integrate them into solar domestic hot water systems, a management task, and a task funding travel to attend the "Field Monitoring for a Purpose" workshop which was held April 2-5, 1990, in Gothenburg, Sweden. The objectives and progress in each task are described in this report.

3. Project Tasks:

TASK 1a. SOLAR HEATING WITH ISOTHERMAL COLLECTOR OPERATION AND
ADVANCED CONTROL STRATEGY

Status: The following specific tasks have been accomplished during the September-October time period:

- Installation of new Hewlett-Packard System 10 PC-based control of collectors.
- Initial test operations with the new controls.
- Investigation of load loop flow.

TASK 1b. SOLAR COOLING WITH SOLID DESICCANT

Status: The following activities were carried out during this period:

- Revision of the 1988 cooling data analysis.
- Finalizing of the report on 1987 and 1988 cooling operations.
- Reloading of ASK desiccant charge.
- Reduction of ASK desiccant wheel speed.
- ASK air flow balancing.

TASK 2. LIQUID DESICCANT COOLING SYSTEM DEVELOPMENT

Status: During this period, the LiBr pump was received and installed. The material used for the piping is PVC and the pipe is of schedule 40. The piece of copper pipe between the dehumidifier and the earlier pump was also replaced by a PVC pipe. The total length of pipe used is 35 foot with 10 valves.

The rotameter on the main line of the regenerator previously gave a full-scale reading in a coupled mode with the earlier pumps. However, as the new pump is expected to increase the flow rate, this rotameter needs replacement.

A figure included within shows the new runs carried out to study the variation of condensation rate with the solution flow rate.

TASK 3. SOLAR HOUSE III - DEVELOPMENT AND IMPROVEMENT OF SOLAR HEATING SYSTEMS EMPLOYING BOILING LIQUID COLLECTORS

Status: The specially designed solar collectors built by Heliodyne have been instrumented and will be installed along with the other new system components in Solar House III by the end of November. Dupont is continuing support of this project with a \$5,000 grant through 1991.

TASK 4. GENERIC SOLAR DOMESTIC WATER HEATING SYSTEMS

Status: Analysis of the drain-back system experimental and TRNSYS data is complete. Installation of the generic anti-freeze system is underway.

TASK 5. ADVANCED RESIDENTIAL SOLAR DOMESTIC HOT WATER (DHW) SYSTEMS

Status: This project was begun in the current contract period at an initially low level of funding. It is DOE's expectation that funding will increase for the next Colorado State University contract beginning December 1, 1990. The Colorado State

University Advanced Systems project was accepted as the United States DHW installation in IEA Task XIV.

TASK 6. MANAGEMENT AND COORDINATION OF COLORADO STATE/DOE PROGRAM

Status: Coordination of research activities continued on the six research tasks under the DOE grant, accounts were maintained and updated, and progress reports were submitted as required.

TASK 7. FIELD MONITORING WORKSHOP

Status: This task has been completed. Possibilities for further work as a result of the workshop are currently being pursued.

TASK 1A. SOLAR HEATING WITH ISOTHERMAL COLLECTOR OPERATION AND ADVANCED CONTROL STRATEGY

Research Team: Charles C. Smith, Task Leader
George Löf, Senior Advisor
Ihsan Abbud, Graduate Research Assistant

Objectives

The primary objective of the solar heating project in Colorado State University Solar House I during the past four years has been to increase operating efficiency of the system using the same solar hardware but with improved control strategy. A companion objective is to improve the comfort and air quality levels of the heated space. Also the project has succeeded in greatly reducing the parasitic electrical power requirements to operate the solar equipment.

During 1985-1988, a series of control system changes increased system efficiencies from 35.7 to 45.1 percent. This was realized at almost no added system cost. The 1989-90 project results are expected to show further improvement in efficiency and comfort.

The existing system operates with two solar energy storage tanks. A low temperature tank receives water flowing from the house heating load circuit and supplies water to the collector circuit. A high temperature tank receives the flow out of the collectors and supplies the heating load. A key element in the current system is a variable speed collector pump. This pump is controlled to maintain a nearly constant collector output temperature. Thus the hot storage tank is maintained at nearly constant temperature.

The principal objective of the 1990 solar heating development under Task 1a is control improvement, cost reduction, and size reduction of a low flow isothermal system.

Work Plan:

1. Investigate alternative low cost control methods and hardware for isothermal collector operation.
2. Design low cost, compact, highly stratified liquid storage.
3. Investigate load loop flow settings/control with respect to isothermal operation.
4. Select and prepare a plan to install new flat plate collectors in 1991.

Progress:

The following specific tasks have been accomplished during the September-October time period:

- Installation of new Hewlett-Packard System 10 PC-based control of collectors.
- Initial test operations with the new controls.
- Investigation of load loop flow.

The new HP data and control system hardware was received in fully functional condition at the beginning of October. It was then possible to begin implementation of the software development that had preceded the hardware delivery.

The new control is established to maintain isothermal collector operation by two procedures. One is to monitor the collector outlet temperature and adjust the collector pump speed to maintain the temperature constant. This method is similar to that of the previous (1989-90) heating season except for some time delay and proportional control functions which are intended to provide smaller temperature variation. The second method of control is to sense the solar radiation level and adjust the flow rate in a prescribed manner which could yield a nearly constant collector outlet temperature. Both methods of control have been initiated and their development will be continued.

Calculations on the optimal load loop flow rate were performed based upon the result of the 1989-90 season. The condition established for this optimum is a temperature of 25°C in water returning from the load. The optimal flow rate depends upon the temperature of hot water supplied to the load loop from the storage tank. Taking the lowest temperature setting during the 1989-90 isothermal test (45°C), the optimal load flow rate is approximately 4 liters per minute. At the highest temperature (65°C), the flow setting should be at 3 liters per minute. The significance of this finding is that the flow rate need not be adjusted with a high level of precision for good system performance. In practice it was difficult to control this flow rate closer than about one liter per minute because of the changing liquid levels in the two storage tanks. The proposed single-tank operation for 1990-91 heating will eliminate this problem even though precise load flow adjustment does not appear essential. Another conclusion is that automatic load flow control would not offer enough advantage to justify its inclusion in the system.

TASK 1B. SOLAR COOLING WITH SOLID DESICCANT

Research Team: Charles C. Smith, Task Leader
George Löf, Senior Advisor
Ihsan Abbud, Graduate Research Assistant

Objectives

Desiccant cooling system research began with the ASK Energymaster unit in the summer of 1987. This first system employed a process known as the Pennington cycle. All of the conditioned air for cooling was taken from the outside. It was dried, cooled, and then rehumidified. This cycle exhibited the expected cooling capacity of the unit (3 tons); however the COP was only 1.0. Next, the SENC cycle was introduced which provides sensible cooling in the recirculated house air duct, and in principle will yield a higher COP. The COP did increase to approximately 1.5; however the capacity dropped substantially to the range of 1.0 to 1.5 tons.

The 1988 testing period was aimed primarily at increasing the capacity of the SENC cycle. The cooling tower was identified as improperly designed for the application. This unit provided too little residence time for the cooling water and wasted much of the drying effect provided by the ASK. The cooling tower was rebuilt with new packing, improved water distribution, and provisions for greater air and water flow adjustments. During the subsequent testing program it was found that the system capacity had not increased, so the duct cooling coil size was increased. Although these changes resulted in some modest improvement in the cooling capacity, the desired 3-ton target was not reached.

Testing of desiccant cooling was not conducted during the 1989-90 program, however important information was generated in an analysis based upon the testing in previous years. The ASK unit is oversized in comparison with the collector capacity and the cooling heat transfer capacity (the cooling tower-duct cooling coil combination). Since the company does not produce a smaller sized unit, it has been necessary to operate the existing unit at significantly reduced air flow. This degrades the overall performance.

The collector size has been increased from 12.5 to 20 square meters since last operating the SENC system in 1988. The cooling heat transfer capacity can be increased. This will allow for testing of a SENC cycle with better matched components.

The analysis also suggests that the SENS cycle (second stage cooling of the supply air out of the ASK unit using cooling tower discharge air - should be considered.

The primary objective of the 1990 solar desiccant cooling project is to determine the changes necessary to yield higher system performance; the goal is a cooling output approaching 3 tons and a COP of 1.5.

Work Plan:

1. The results of the 1988 tests will be analyzed in detail, and the significant findings will be reviewed with industry (ASK) engineers.
2. Based on analysis of the results and on information from industry specialists, design and specify changes in the system which will lead to increased capacity.
3. Short term testing of existing components will be carried out late in the 1990 cooling season.

Progress:

The following activities were carried out during this period:

- Revision of the 1988 cooling data analysis.
- Finalizing of the report on 1987 and 1988 cooling operations.
- Reloading of ASK desiccant charge.
- Reduction of ASK desiccant wheel speed.
- ASK air flow balancing.

Effort on Task 1b was focused on the recommended changes to the ASK unit for improved performance. The recommendations based on the 1988 cooling operation included reducing the desiccant wheel speed and changing the ratio of regeneration to process air flow from 1.0 to approximately 0.8. An ASK engineering representative concurred with these changes and also recommended reloading the desiccant charge in the unit.

All three recommendations were implemented in September and completed by September 27. The air balancing and wheel speed adjustments required air monitoring checks and speed reduction design. The desiccant loading appeared to be a significant factor, since nine pounds, or nearly half of the original 20-pound charge, were required. Limited testing before and after the changes indicates improvement.

The onset of cold weather prevented testing at high ambient temperature and humidity.

TASK 2. LIQUID DESICCANT COOLING SYSTEM DEVELOPMENT

Research Team: Terry G. Lenz, Task Leader
Shailesh Potnis, Ph.D. Graduate Student

Objectives:

The following objectives have been met on this open-cycle liquid desiccant research:

1. Quantified the separate contributions of the spray sections and packed sections to overall mass transfer for both the regenerator and dehumidifier. This is the first time separate contributions to mass transfer for spray and packing have been determined for such composite spray/packed liquid desiccant contact units.
2. Determined that both the liquid and gas-side resistance to mass transfer are important in the regenerator.
3. Carried out a partial factorial statistical experimental study of the packed bed dehumidifier yielding the relative importance of key operating parameters on unit performance.
4. Completed converting piping, measuring, and pumping components to plastic construction. We now have a system in which nearly all components are constructed of low-cost plastic materials compatible with handling corrosive brines.

Although we have a good deal of operating experience with our open-cycle liquid desiccant dehumidification system, additional effort is needed to assemble and operate a complete, optimum system. Specific studies we feel are important toward achieving proper understanding for an optimally designed liquid desiccant cooling system are included in the Work Plan below.

Work Plan:

1. Assess the performance of alternate packing materials, such as Munters packing, in pursuit of improved mass transfer for both the regenerator and dehumidifier, at minimum pressure drop.
2. Add piping and instrumentation to permit long steady-state study for coupled regenerator-dehumidifier operation.
3. Discussions with Kathabar Company have indicated that the regenerator may perform better in a cocurrent rather than countercurrent mode for a hot-air energy source. No one has made such a comparison of these alternate operating modes, and our system should permit this study with minor modifications.

Progress:

During this period, the LiBr pump was received and installed. The material used for the piping is PVC and the pipe is of schedule 40. The piece of copper pipe between the dehumidifier and the earlier pump was also replaced by a PVC pipe. The total length of pipe used is 35 foot with 10 valves.

The rotameter on the main line of the regenerator previously gave a full-scale reading in a coupled mode with the earlier pumps. However, as the new pump is expected to increase the flow rate, this rotameter needs replacement.

Figure 1 shows the new runs carried out to study the variation of condensation rate with the solution flow rate. It can be observed that the condensation rate corresponding to a flow rate of 0.606 kg/s is significantly higher than the curve obtained from the earlier data points. This difference may be due to the change in the method employed in calculating the condensation rate for this particular point. The condensation rate at this point was calculated using the enthalpy change of solution in the cooling unit which was not true for the other points. This was done to avoid an error recently observed due to a faulty temperature measurement at the dehumidifier outlet. The enthalpy change of the solution across the cooling unit is usually higher by 10-20 percent than the enthalpy change for the water (likely due to inadequate insulation). This run will be repeated in the future to obtain a condensation rate by the same method as other points. An energy balance was also carried out for the last decoupled run (solution flow rate = 0.87 kg/s) and the error was 13.5 percent.

One of our primary objectives is to nondimensionalize the data shown in Figure 1 in a format consistent with standard correlations using Sherwood and Reynolds numbers. Reynolds number can be based on the thickness of the packing, diameter of the packing as a solid sphere, and the tower diameter. The Sherwood number will also change accordingly. At present, a literature survey is being carried out to obtain the diffusivity of water in LiBr solutions required to calculate Sh.

The air flow meter was found to give some inconsistent readings, so it was recalibrated.

Figure 1

TASK 3. SOLAR HOUSE III - DEVELOPMENT AND IMPROVEMENT OF SOLAR HEATING SYSTEMS EMPLOYING BOILING LIQUID COLLECTORS

Research Team: Jane H. Davidson, Task Leader
Howard A. Walker, Graduate Research Assistant
Eugenia Vieira, Graduate Research Assistant

Objectives

Optimize the design and operation of boiling collector hot water/space heating systems to substantially increase system efficiency and reliability and eliminate reliance on environmentally unsafe refrigerants. Characterize the performance of flat-plate solar collectors during two-phase operation with R-123.

Work Plan

1. Build and instrument an optimized self-pumping system in Solar House III.
2. Initiate experimental study of the operation of the optimized system with alternative refrigerant R-123.
2. Assess the performance characteristics of two-phase collectors with R-123 using a separate test loop and analytical modeling.
3. Compare the self-pumping system to conventional domestic hot water systems on the basis of performance and economics.
4. Provide bimonthly progress reports. A final report will be submitted in March during the next grant period.

Progress:

Instrumentation and installation of the two-phase, self-pumping system is progressing. Two specially designed solar collectors built by Heliodyne, Inc. and shown in Figure 2 have been instrumented with Teflon-coated thermocouples. The first generation system has been removed from Solar House III and the newly designed system shown in Figure 3 will be installed by the end of November. The in-tank, finned, double-walled heat exchanger design is completed and one unit ordered from Energy Transfer, Inc.

Dupont has extended their support of the project through 1991 with an additional \$5,000 gift in support of the research from the Freon Products Division. This cash award is in addition to the gift of any required quantity of alternative refrigerant R-123.

A theoretical Second Law analysis of the system has been initiated.

Figure 2.

Figure 3.

TASK 4. GENERIC SOLAR DOMESTIC WATER HEATING SYSTEMS

Research Team:

William S. Duff, Task Leader
Jane Davidson, Task Leader
William Carlson, Graduate Research Assistant
Graduate Research Assistant

Objectives

1. Cooperatively establish a methodology by which manufacturers and installers of solar domestic hot water (SDHW) systems can obtain an SRCC rating, without retesting, when a component in the originally tested system is changed.
2. Provide detailed system and component data that will enable the research team at the University of Wisconsin to confidently apply numerical simulation models to various SDHW component assemblies.
3. Based on successful outcome of rating methodology for SDHW systems, develop rating methodology for rating generic solar space heating systems.

Work Plan

1. Complete the planned testing of the drain-back generic system. Testing of the recirculation and anti-freeze systems will be completed under a subsequent grant.
2. Provide data to the University of Wisconsin to assist in the development of numerical simulation models of the drain-back system. The numerical models will be used by University of Wisconsin to provide ratings for the DHW systems with fixed components and in fixed locations.
3. Provide an interim report to DOE which includes results and analysis of the drain-back system.

Progress:

Analyses of the 16 experimental SRCC trials of the generic drain-back system have been completed. Tables 1, 2, 3 and 4 summarize the experimental and TRNSYS results as well as the differences between the two.

The comparison of the experimental data and TRNSYS data shown in the Figures 4, 5, 6 and 7 indicates that there is a bias between the two rating methods. The magnitudes of the measured biases for the four energy quantities Q_s , Q_{net} , Q_{aux} , and Q_u , are 1490 kJ, 1110 kJ, 1000 kJ and 600 kJ, respectively. It is impossible to determine the source of these biases from the summary energy quantities alone. However, it is evident in comparing the experimental values of total energy delivered Q_{del} to the corresponding TRNSYS values, that the volume-based hot water draw used by TRNSYS does not adequately match the SRCC specified energy-based draw.

Table 1 Summary of Experimental Results

Trial	Collector		Recirculation Flow		Collector		Storage Tank		SF (%)	Q _{del} (kJ)	Q _s (kJ)	Q _{net} (kJ)	Q _{res} (kJ)	Q _{aux} (kJ)	Q _{par} (kJ)	Q _u (kJ)
	Flow Rate (l/s)	Rate (l/s)	Rate (l/s)	Area (m ²)	Volume (l)	Design	Tank	Volume (l)								
1	.057	.047	.047	2.78	250	Basic	Basic	250	22.5	49820	16647	11212	12309	39329	5435	17554
2	.114	.047	.047	2.78	250	Manifold	Manifold	250	26.0	49815	19545	12981	14881	35480	6564	18196
3	.057	.095	.095	2.78	250	Manifold	Manifold	250	24.0	49811	17975	11946	12772	37107	6028	18254
4	.114	.095	.095	2.78	250	Basic	Basic	250	23.0	49821	16996	11464	13157	38182	5532	18401
5	.057	.047	.047	5.56	250	Manifold	Manifold	250	40.8	49811	26382	20331	18712	29312	6051	29369
6	.114	.047	.047	5.56	250	Basic	Basic	250	40.2	49815	25471	20008	18752	29529	5463	30681
7	.057	.095	.095	5.56	250	Basic	Basic	250	37.0	49829	24260	18890	19577	31449	5369	29794
8	.114	.095	.095	5.56	250	Manifold	Manifold	250	42.3	49811	27273	21072	19299	28370	6202	30047
9	.057	.047	.047	2.78	310	Manifold	Manifold	310	24.9	49811	18459	12394	14334	37265	6066	18223
10	.114	.047	.047	2.78	310	Basic	Basic	310	24.1	49822	17717	11993	14784	37753	5724	18083
11	.057	.095	.095	2.78	310	Basic	Basic	310	20.7	49816	16968	11312	14999	38675	5656	18088
12	.114	.095	.095	2.78	310	Manifold	Manifold	310	24.6	49822	18482	12255	14808	36684	6227	19084
13	.057	.047	.047	5.56	310	Basic	Basic	310	39.6	49811	25113	19706	20402	30635	5408	29796
14	.114	.047	.047	5.56	310	Manifold	Manifold	310	43.1	49815	27686	21474	21998	27642	6213	31304
15	.057	.095	.095	5.56	310	Manifold	Manifold	310	41.9	49815	26956	20877	21686	28681	6079	30125
16	.114	.095	.095	5.56	310	Basic	Basic	310	42.6	49822	26712	21228	23378	29013	5484	31746

Table 2 Experimental Measurement Error Based on Two Standard Errors

Trial	Collector		Recirculation		Collector Area (m ²)	Storage Tank Volume (l)	Storage Tank Design	Q _{td} (kJ)	Q _s (kJ)	Q _{net} (kJ)	Q _{res} (kJ)	Q _{aux} (kJ)	Q _{tar} (kJ)	Q _u (kJ)
	Flow Rate (l/s)	Flow Rate (l/s)	Flow Rate (l/s)	Flow Rate (l/s)										
1	.057	.047	.047	.047	2.78	250	Basic	393	173	185	123	216	66	1103
2	.114	.047	.047	.047	2.78	250	Manifold	393	192	207	145	190	77	1103
3	.057	.095	.095	.095	2.78	250	Manifold	393	181	195	121	198	72	1113
4	.114	.095	.095	.095	2.78	250	Basic	393	174	186	129	207	64	1031
5	.057	.047	.047	.047	5.56	250	Manifold	393	239	249	165	157	72	1756
6	.114	.047	.047	.047	5.56	250	Basic	393	231	240	167	162	64	1657
7	.057	.095	.095	.095	5.56	250	Basic	393	223	232	177	171	64	1647
8	.114	.095	.095	.095	5.56	250	Manifold	393	245	255	168	153	72	1736
9	.057	.047	.047	.047	2.78	310	Manifold	391	184	198	179	199	72	1094
10	.114	.047	.047	.047	2.78	310	Basic	392	179	191	146	204	67	1051
11	.057	.095	.095	.095	2.78	310	Basic	392	173	186	152	207	67	1069
12	.114	.095	.095	.095	2.78	310	Manifold	392	184	198	142	193	72	1118
13	.057	.047	.047	.047	5.56	310	Basic	393	230	239	183	165	65	1658
14	.114	.047	.047	.047	5.56	310	Manifold	393	247	257	193	148	72	1744
15	.057	.095	.095	.095	5.56	310	Manifold	392	242	253	191	153	72	1754
16	.114	.095	.095	.095	5.56	310	Basic	393	241	249	208	158	64	1630

Table 3 Summary of Numerical Results

Trial	Collector		Recircula		Storage		SF (%)	Q _{tot} (kJ)	Q _s (kJ)	Q _{net} (kJ)	Q _{aux} (kJ)	Q _{pr} (kJ)	Q _u (kJ)
	Flow Rate (l/s)	Area (m ²)	Flow Rate (l/s)	Volume (l)	Tank Design	Tank Design							
1	.057	2.78	.047	250	Basic	Basic	20.5	49230	15620	10068	37510	5552	18150
2	.114	2.78	.047	250	Manifold	Manifold	23.1	49230	16830	11345	36660	5485	18830
3	.057	2.78	.095	250	Manifold	Manifold	21.4	49230	15990	10553	37180	5437	18630
4	.114	2.78	.095	250	Basic	Basic	21.9	49570	16240	10840	37140	5400	18760
5	.057	5.56	.047	250	Manifold	Manifold	39.7	49230	24920	19520	27410	5400	30630
6	.114	5.56	.047	250	Basic	Basic	39.7	49230	24930	19530	27220	5400	31020
7	.057	5.56	.095	250	Basic	Basic	38.1	49230	24150	18750	28910	5400	30410
8	.114	5.56	.095	250	Manifold	Manifold	42.1	49230	26140	20740	26930	5400	31950
9	.057	2.78	.047	310	Manifold	Manifold	21.4	49230	16330	10532	36830	5798	18700
10	.114	2.78	.047	310	Basic	Basic	21.1	49230	15970	10395	37190	5576	18620
11	.057	2.78	.095	310	Basic	Basic	20.2	49230	15470	9922	37660	5548	18320
12	.114	2.78	.095	310	Manifold	Manifold	22.5	49570	16540	11140	35870	5400	19100
13	.057	5.56	.047	310	Basic	Basic	36.7	49230	23470	18070	28340	5400	30060
14	.114	5.56	.047	310	Manifold	Manifold	42.5	49230	26300	20900	27440	5400	32300
15	.057	5.56	.095	310	Manifold	Manifold	39.4	49230	24780	19380	28420	5400	31190
16	.114	5.56	.095	310	Basic	Basic	40.0	49230	25110	19710	28440	5400	31720

Table 4 Differences Between Experimental and Numerical Results

Trial	Collector		Recirculation Flow Rate (l/s)	Collector Area (m ²)	Storage Tank Volume (l)	Storage Tank Design	Q _s (kJ)	Q _{net} (kJ)	Q _{aux} (kJ)	Q _{par} (kJ)	Q _u (kJ)
	Flow Rate (l/s)	Flow Rate (l/s)									
1	.057	.047	.047	2.78	250	Basic	1027	1144	1819	-117	-596
2	.114	.047	.047	2.78	250	Manifold	2715	1636	-1180	1079	-634
3	.057	.095	.095	2.78	250	Manifold	1985	1393	-73	591	-376
4	.114	.095	.095	2.78	250	Basic	756	624	1042	132	-359
5	.057	.047	.047	5.56	250	Manifold	1462	811	1902	651	-1261
6	.114	.047	.047	5.56	250	Basic	541	478	2309	63	-339
7	.057	.095	.095	5.56	250	Basic	110	140	2539	-31	-616
8	.114	.095	.095	5.56	250	Manifold	1133	332	1440	802	-1903
9	.057	.047	.047	2.78	310	Manifold	2129	1862	435	268	-477
10	.114	.047	.047	2.78	310	Basic	1747	1598	563	148	-537
11	.057	.095	.095	2.78	310	Basic	1498	1390	1015	108	-232
12	.114	.095	.095	2.78	310	Manifold	1942	1115	814	827	-16
13	.057	.047	.047	5.56	310	Basic	1643	1636	2295	8	-264
14	.114	.047	.047	5.56	310	Manifold	1386	574	202	813	-996
15	.057	.095	.095	5.56	310	Manifold	2176	1497	261	679	-1065
16	.114	.095	.095	5.56	310	Basic	1602	1518	573	84	26

Figure 4 Comparison of Experimental Measurement and Numerical Simulation of Daily Delivery of Solar Energy, Q_s . Error Bands are Two Standard Deviations of the Calculated Measurement Error.

Figure 5 Comparison of Experimental Measurement and Numerical Simulation of Daily Net Delivery of Solar Energy, Q_{net} . Error Bands are Two Standard Deviations of the Calculated Measurement Error.

Figure 6 Comparison of Experimental Measurement and Numerical Simulation of Daily Auxiliary Energy, Q_{aux} . Error Bands are Two Standard Deviations of the Calculated Measurement Error.

Figure 7 Comparison of Experimental Measurement and Numerical Simulation of Daily Useful Collected Energy, Q_u . Error Bands are Two Standard Deviations of the Calculated Measurement Error.

The TRNSYS value of Q_{del} is 1 percent less than the amount specified by SRCC. This discrepancy between numerical and experimental data can account for as much 14 percent of the bias.

There are several other possible sources of bias including modeling of heat transfer from the pumps to the water, modeling of drain-back tank and piping thermal losses (particularly losses from piping and the drain-back tank, since loss coefficients from these components were not experimentally measured), and instrumentation error.

An interim report detailing the drain-back system analysis will be submitted at the December heating review.

The experimental procedure has been modified to switch system operation to the anti-freeze system.

Discussions and a meeting were held with Jay Burch of SERI concerning the implementation of the rating methodology.

TASK 5. ADVANCED RESIDENTIAL SOLAR DOMESTIC HOT WATER (DHW) SYSTEMS

Research Team: William S. Duff, Task Leader
Jane Davidson, Associate Task Leader
Graduate Research Assistant

Objectives:

- 1) Compile and evaluate promising advanced solar domestic hot water components and concepts.
- 2) Integrate promising advanced components and concepts into conceptual solar domestic hot water systems.
- 3) Analyze the most promising systems in terms of thermal performance, cost effectiveness, and reliability.
- 4) Based on these analyses, design advanced solar domestic hot water system prototypes which can be manufactured commercially.
- 5) Analyze and experimentally evaluate these prototypes to establish their performance, cost, reliability, and maintainability advantages.
- 6) Set up a procedure whereby the United States solar industry will receive timely information regarding new solar domestic hot water components and concepts.

Work Plan:

- 1) Evaluate and select the most promising advanced solar domestic hot water components and concepts. Advanced components and concepts will be those developed by the investigators, contributed by United States industry, proposed in advanced systems research initiatives, and adapted from ideas of others in the United States, Europe, Japan, and elsewhere.
- 2) Perform preliminary analyses to determine the best ways to integrate the selected components and concepts into solar domestic hot water systems so as to best balance the goals of low initial cost, high performance, high reliability, low maintenance, and low operating cost.
- 3) Based on these analyses, design advanced solar domestic hot water systems that best meet the goals. The design process will also address component sizing, freeze protection, overheating prevention, material selection, good practice in overall system integration, and consumer acceptance.
- 4) Build and experimentally evaluate promising systems.
- 5) Using the generic DHW system project's data acquisition and automated testing hardware and software as the nucleus, establish a solar

domestic hot water system testing facility at the Solar Energy Applications Laboratory.

- 6) Establish a testing methodology of several weeks' duration which would provide estimates of seasonal performance that are within ± 1 percent of predictions from complete annual simulations.
- 7) Establish a procedure for timely dissemination to United States manufacturers of this information and other information on worldwide advances in solar domestic hot water systems, especially from Europe and Japan.
- 8) Participate as a United States installation in the International Energy Agency Solar Heating and Cooling Program's Task XIV -- Advanced Active Solar Energy Systems.

This project is a multi-year effort, with the selection, system design, and testing process being repeated several times and with parts of the process occurring in parallel. Conceptual evaluation, selection and design of advanced components, concepts, and systems will be performed in cooperation with SERI.

In this contract, only the organizational aspects of items 1, 2 and 3 and items 7 and 8 of the above project approach would be included. The remaining efforts would be included in subsequent contracts.

Progress:

This project was begun in the current contract period at an initially low level of funding. It is DOE's expectation that funding will increase for the next Colorado State University contract beginning December 1, 1990. The Colorado State University Advanced Systems project was accepted as the United States DHW installation in IEA Task XIV.

We have the responsibility of Lead Country for the Project Reporting Task Force. As part of this responsibility, revised Task XIV project approval formats were sent to each participant.

TASK 6. MANAGEMENT AND COORDINATION OF COLORADO STATE/DOE PROGRAM

Research Team: Douglas C. Hittle, Director
George Löf, Senior Advisor
Janice Stapleman, Administrative Assistant

Objective

Coordinate SEAL-DOE task efforts, provide assistance to DOE, and attend programmatic meetings as requested by DOE.

Work Plan

1. Collaborate with leaders of the five technical tasks in coordination of SEAL program.
2. Organize team and sub-team planning sessions necessary for the conduct of the tasks.
3. Provide and manage necessary facilities and services to leaders and personnel involved in each task.
4. Provide timely bimonthly reports on all tasks as required by contract.
5. Maintain fiscal control of program.
6. Attend meetings and technical reporting sessions as requested by DOE.
7. Respond to DOE requests for information on solar equipment and its operation, for review of reports, and for panel and committee participation.
8. Provide technical consultation from director and senior advisor to task leaders and research personnel.
9. Participate in IEA Solar Heating Advisory Group Meeting in Stuttgart, Germany.

Progress:

On October 30, SEAL Director Doug Hittle wrote a letter to John Millhone, Deputy Assistant Secretary of the DOE Office of Building Technology, which outlined the research efforts that SEAL will propose for the next SEAL-DOE contract and requested his assistance in identifying appropriate sources within DOE for funding those research projects. The current SEAL-DOE research grant expires November 30, 1990.

At a SEAL staff meeting on October 11, visiting professor Tor Malmström from Sweden discussed solar research in his country and outlined his research efforts here at SEAL.

Coordination of research activities continued on the six research tasks under the DOE grant, accounts were maintained and updated, and progress reports were submitted as required.

TASK 7. FIELD MONITORING WORKSHOP

Research Team: Dr. William S. Duff

Objective and Work Plan:

Professor Duff was nominated by the International Energy Agency Solar Heating and Cooling Program and the United States Department of Energy to attend the "Field Monitoring for a Purpose" workshop which was held April 2-5, 1990, in Gothenburg, Sweden. The workshop was sponsored by three International Energy Agency organizations: (1) the Solar Heating and Cooling Program, (2) the Program for Energy Conservation in Buildings, and (3) the Center for the Analysis and Dissemination of Demonstrated Energy Technologies. A paper was to be presented in the workshop.

Progress:

This task has been completed. Possibilities for further work as a result of the workshop are currently being pursued.

END

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