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Executive Summary

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Colorado State University

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SOLAR HEATING AND COOLING SYSTEMS

OPERATIONAL RESULTS CONFERENCE

EXECUTIVE SUMMARY

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THE BROADMOOR HOTEL
Colorado Springs, Colorado
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ABSTRACT

The Solar Heating and Cooling Systems Operational Results Conference is the first major conference dealing exclusively with the results of complete, integrated heating and/or cooling systems. Reports on system performance have drawn heavily on the output of the National Solar Data Program and include specific analyses of this data by the Department of Housing and Urban Development (HUD), IBM-Huntsville (a prime contractor of the Department of Energy's Solar Data Program), and others. As such it provides a large body of information on the technical and economic performance of solar energy systems and clearly highlights many of the accomplishments and difficulties of the emerging solar energy industry. Specific results included:

- Well engineered and properly installed solar systems displayed generally trouble-free operation and high thermal performance, although in some cases the performance was short of predictions.

- Commercial-sized units typically performed better than residential installations, primarily due to a severe lack of engineering and adherence to proper installation procedures in the residential applications. Because of this lack of good design and installation, many of the residential systems did not perform anywhere near expectations.

- Systems, in general, did not perform as expected or as predicted by design models, i.e., overall system performance was less than the sum of the components and subsystems' performance. The results of poor overall performance were due in many cases to a poor matching or integration of components.

- Passive solar heating systems appeared to perform better and more trouble-free than active systems. However, the wider range of acceptable comfort conditions, the less critical evaluation of the passive systems, and the lack of substantial performance data on passive systems (i.e., a lack of adequate data instrumentation and sufficient numbers of well-instrumented installations) prohibit any definitive conclusions on active vs. passive systems.

- Problems in solar systems generally fell into two areas: Design deficiencies and/or inadequate or improper installation procedures. Many of the problems of design, installation, durability, and reliability were reported on and categorized. Proper installation was shown to be much more critical in solar heating and cooling systems than in conventional installations.

- Designers generally failed to recognize the importance of minimizing parasitic electrical power requirements of the solar system operations. This resulted in many systems utilizing unacceptable amounts of electrical energy in operating the solar system.

- Thermal losses from storage units, piping and /or ducting, and other solar components were excessive and usually unexpected. Few designers and/or installers realized the potential magnitude of the problem and consequently did little to account for excessive heat losses. As a result, system efficiencies were greatly reduced.

- Control subsystems failures, malfunctions, and deviations from designed modes of operation caused significant and in some instances disastrous effects on the solar system's thermal performance. In this respect, simpler designs performed better than complex designs. It should be noted that simple designs as used here implies a simple control logic and does not imply the nonuse of sophisticated hardware (e.g., solid state controllers).

- Inadequate training of installation personnel was demonstrated to be a major cause of poor system installation and ultimate performance. It should be noted, however, that many cases of inadequate installation were due to a lack of proper specifications by the designer, and not necessarily due to a careless installer.

- Poor choice of materials by designers was shown to be important in system performance and durability.

- Reports on system costs indicated the need for further cost reductions in solar system fabrication and installation. Installation costs were shown to vary widely and to be a major unknown in predicting future costs.

Analysis of comments by attendees to the conference indicated that federally funded demonstration projects were less cost-effective and more likely to incur operating difficulties than were nondemonstration program projects. Data gathered within the Federal Demonstration Program (by the National Solar Data Program) was, however, considered invaluable in the development of the solar energy industry.

INTRODUCTION

The Solar Heating and Cooling Systems Operational Results Conference held at the Broadmoor Hotel, Colorado Springs, Colorado, in November 1978, constitutes the first major conference on heating and cooling systems for buildings. For the first time complete, integrated systems encompassing heat sources, auxiliary and supplementary equipment, and heating/cooling distribution subsystems, were analyzed and discussed in detail. While there exists a large body of information on components and subsystems, there has been a severe lack of systems engineering and development where all components and subsystems are integrated. This has been particularly true in residential applications.

The results of the conference demonstrated this lack of engineering of the complete system. In addition, poor understanding of solar heating and cooling principles and a lack of adequate training resulted in poor performance due to careless installations. In general, too many systems were engineered and installed by personnel with inadequate solar training, HVAC skills, and/or experience.

This report attempts to summarize the results of solar heating and cooling systems operating performance as presented at the Broadmoor Conference. The report considers the reported performance of residential, commercial, and passive systems; the lessons to be learned in design, installation, operation, and maintenance procedures; and the findings of cost and benefit analyses. The report concludes with general recommendations for improving performance and with some broad conclusions concerning the results of the conference. The reader is encouraged to consult individual papers for specific and detailed recommendations and conclusions.

The conference reports are based in large part on information provided by the National Solar Data Program, and thus reflect a bias on the reported results by referring, in most cases, to federally funded projects involved in the National Demonstration Program. It is apparent that the operating performance of the demonstration program projects were, in general, of a lower quality than nondemonstration program projects. This fact is due in part to the tendency of the Demonstration program to fund unique, innovative, and relatively untried systems, whereas nonfederally funded systems were selected on a more conservative basis. Consequently, it is necessary to note these factors in evaluating the results of poorer system performance of some installations.

Appendix A of this report details some of the reaction and opinions of the conference results and objectives by attendees. It should be noted that the conference hosted representatives from 42 states.

PERFORMANCE RESULTS--RESIDENTIAL

The operational performance of residential solar heating and cooling systems were, in general, considerably below expectations. Many of the active solar heating systems experienced problems with collection, storage, distribution, and control. Of 30 projects funded by HUD, 12 were heating systems which delivered only 5% to 8% of the incident solar energy. Four of the HUD DHW

Table 1

HUD RESIDENTIAL SOLAR HEATING SYSTEMS PERFORMANCE ANALYSIS [1]*

Installation	Incident Solar (10^6 Btu)	Solar Collected (10^6 Btu)	Solar Collector Efficiency (%)	Energy to Storage (10^6 Btu)	Energy From Storage (10^6 Btu)	Storage Efficiency (%)	Solar Delivered To Load (10^6 Btu)	System Efficiency (%)
Space and DHW Heating--Liquid Collectors								
1	47.4	11.9	25.2	11.9	4.7	39.1	4.7	9.8
2	10.4	1.6	15.0	0.9	0.8	83.2	0.8	7.5
3	152.9	45.1	29.5	41.3	11.1	26.9	11.1	7.3
4	53.9	10.4	19.2	9.1	3.4	37.7	10.0	18.5
5	83.4	15.5	18.6	10.9	2.0	18.6	2.2	2.7
6	11.5	1.6	13.8	1.5	0.1	3.2	0.0	0.0
Totals	359.5	86.1	23.9	75.8	22.1	29.1	28.8	8.0
Space and DHW Heating--Air Collectors								
1	68.1	12.5	18.3	11.5	3.0	26.4	2.7	4.0
2	23.9	5.1	21.6	2.3	0.8	35.1	1.8	7.7
3	113.1	32.8	29.0	28.6	3.1	10.9	7.2	6.4
4	79.2	7.0	8.9	5.4	0.0	0.0	1.6	2.0
5	38.7	7.3	18.9	4.5	0.5	11.8	1.0	2.6
6	32.2	4.4	13.7	5.0	3.4	67.9	3.4	10.6
Totals	355.1	69.2	19.5	57.3	10.9	19.0	17.8	5.0
DHW Heating								
1	301.9	99.8	33.0	77.9	45.5	58.0	42.3	14.0
2	152.1	66.1	43.4	59.7	43.7	73.0	44.2	29.0
3	21.2	6.0	28.4	6.0	5.5	92.0	5.5	26.1
4	130.1	34.6	26.5	34.6	29.3	85.0	29.3	22.4
Totals	695.3	206.4	34.1	178.2	124.0	69.6	121.3	20.0

*Results based on information from the National Solar Data Program.

systems delivered 20% of the incident energy to load. Table 1 is taken from Freeborne [1] (based on information obtained in the National Solar Data Program), and shows a representative sample of the results.

The lower system efficiencies were due in part to excessive thermal storage losses (either in the form of heat conduction or hot air leakage). Storage system efficiencies (storage loss divided by storage input) ranged from 29% for space heating and DHW heating--liquid collectors--to 19% for air systems to 70% for DHW systems. DHW heating systems have lower thermal storage heat losses due to a better time synchronization of solar availability and demand load. Air systems have low (UA) values for storage heat loss, but damper leakage resulted in substantial heat losses.

It should be noted that in the calculation of system efficiency, storage heat losses to the interior of the building are excluded. In fact, much of these losses are "useful." The criterion as to the usefulness of storage losses can be based on whether or not the house temperature is above the thermostat setting. When this situation occurs, predominantly in the spring and fall, these storage losses are no longer useful. Of course, heat losses from storage to the building's interior in the cooling season are detrimental to the system's performance and not only reduce the ability of the solar system to provide useful cooling but actually add to the cooling load.

The reduced system efficiencies are also due in part to lower than expected collector efficiencies. Table 2 lists several comparisons of predicted and actual collector efficiencies, storage losses as a percent of the useful solar collected heat, and resulting system efficiencies. Note that the system efficiencies also include the effects of heat losses from piping and other solar components as well as thermal storage heat losses. The data is taken from the demonstration program as monitored by IBM and the National Solar Data Program.

Table 2

REPORTS OF COLLECTOR AND SYSTEM EFFICIENCIES

(From the National Solar Data Program and as Reported by IBM)

Collector Efficiency Predicted (%)	Collector Efficiency Actual (%)	Storage Thermal Loss (percent of useful solar collected) (%)	Solar System Efficiency (%)	Solar System COP*	Reference Author/Installation
48.3	28.0	31.4	19.2	4.7	Nemetz [2]/DHW Heating
43.8	32.0	77.5	7.2		McCumber [3]/ Space & DHW Heating
72.5	43.5	25.0	15.2	47.2	McCumber [4]/ DHW (Apartments)
47.5	25.0	60.0	10.0		Lee [5]/ Heating & Cooling, DHW
42.9	25.0	40.0	15.0	1.5	Hancock [6]/ Heating, Cooling, DHW

*COP = Total useful solar heat delivered to load/Total electrical power for solar operations

From Table 2, we see the continued high level of thermal storage losses (the DHW system's heat losses are all nonuseful heat to load and in one case implied a tank insulating value of R = 1 hr ft °F/Btu). In addition, we see the effect of substantially reduced collector efficiencies. McCumber [7] did a comparative analysis of the predicted and actual outputs of seven different solar collector arrays and found errors of -54.2% to -4.6%. Excluding the best flat plate, which McCumber felt was inconsistent with the majority, the average deviation from predicted values was -28.5%.

In addition to thermal storage heat losses and poorer collector performance, substantial energy losses were encountered in piping and ducting. Ward [8] did an analysis of 24 solar homes in a single subdivision. Table 3 provides a summary of heat losses and heat delivered to load. Ward then noted that the addition of two inches of piping insulation would increase the performance substantially (see last two columns of Table 3).

Table 3

PERFORMANCE DATA ON 24 SOLAR HOMES—WARD [8]

	Actual Results		Revised*	
	Total Energy (10^6 Btu)	Percent of Useful Solar (%)	Total Energy (10^6 Btu)	Percent of Useful Solar (%)
Solar energy collected	5.92	100	5.92	100
Energy lost between collectors and storage	2.30	39	0.77	13
Storage losses	1.67	28	1.67	28
Energy lost between storage and load	0.34	6	0.11	2
Solar energy delivered to space heating load (controlled)	1.09	18	2.85	48
Solar energy delivered to DHW heating load	0.48	8	0.48	8

*With addition of 2-inch insulation on piping.

In addition to low system efficiencies, the residential applications reports indicated excessive electrical power requirements to operate the solar system. This is shown in Table 2 for several of the reported systems and also in Table 4. Systems COP's should exceed 15 or 20 in order to compete technically and economically with conventional electrical heating and cooling systems with COP's of 1 to 4. In Table 2, only the large-scale (commercial-sized) DHW heating system is competitive with conventional systems. In Table 4, the space heating systems are only marginally competitive, and the space cooling unit is not economically feasible. It should be pointed out, however, that Ward et al. [14] indicated design modifications which could be expected to

achieve a system COP of 17-20 for space cooling, making the system competitive.

Table 4

EFFICIENCIES AND SYSTEM COP FOR OTHER REPORTED SYSTEMS

Installation	Collector Efficiency (%)	Storage Losses (as percent of useful solar collection) (%)	System Efficiency (%)	System COP*	Reference Author/Installation
1	33.6	13.4	29.1	10.5	Karaki [9]/ Space Heating--Air
2	18.1	43.5	10.2	8.3	Hedstrom et al. [10]/ Space Heating
3	26.3	5.8-9.3	23.5-24.4	11.2-7.8	Leverenz et al. [11]/ Space Heating
4	27.8	5-15	24-26	5.0	Erdmann et al. [12]/ Space Heating
5	30.0	36.7	19.0	2.2	Bedinger et al. [13]/ Space Heating
6	50.7	19.4	23.0	6.7	Ward et al. [14]/ Space Cooling

*System COP $\frac{\text{Total useful solar}}{\text{Total electrical power to operate solar system}}$ and/or

Table 4 is also noteworthy in that for the experimental systems (installation numbers 1, 3, 4, and 6), which were more heavily engineered than demonstration systems, the storage heat losses were much lower and system efficiencies were considerably higher. It is thus evident that properly engineered and installed solar heating and cooling systems can be technically and economically competitive.

PERFORMANCE RESULTS--COMMERCIAL

The operational performance of commercial solar heating and cooling systems was significantly better than the residential installations. This is due in part to the increased engineering design of the larger systems. Table 5 summarizes the major commerical projects reported on at the conference.

Table 5

RESULTS OF COMMERCIAL SOLAR HEATING AND COOLING SYSTEMS

Installation	Collector Efficiency (%)	Storage Losses (as percent of useful solar collected) (%)	Solar System Efficiency (%)	Solar System COP	Reference Author/Installation
1	15.0	27.2	7.2		Wallace [15]/ Space Cooling
2	26.4	15.5	25.5	13.2H 3.5C	Hedstrom et al. [16]/ Space Heating and Cooling
3	25.7	20.1	21.0		Jensen [17]/ Space Heating and Cooling
4	34.0	3.0	33.3	35.3	Aquila [18]/ DHW--Restaurant
5	26.0	13.0	22.0	47.3	Armstrong [20]/ DHW--Laundry
6	17.6	40.0	11.9		Crum [21]/ Heating (and Cooling) and DHW--Dormitory
*7	30.0	20.4 72.5	26.4 7.5	10.0 12.5	Murray et al. [22]/ Heating-- Community Center
8	40.0	14.2	34.3	1.73	Fenton et al. [23]/ Heating and Cooling-- Office Building

*1st figures are for when fraction of load is 0.63.
2nd figures are for when fraction of load is 0.91.

Installations #1 and #6 utilized concentrating solar collectors and #6 used a continuous flow through the collector 24 hours per day. These more unusual designs demonstrated significantly poorer performance. In one case (#6) the continuous circulation of collector liquid resulted in 32% of the collected energy being reradiated to the ambient at night.

Also noteworthy is the reduction in Solar System COP from the heating value (13.2) to that for cooling (3.2) in Installation #2. This indicates a need for simplification and reduction of pumps, etc., in the solar cooling subsystems.

Installation #7 provides a clear indication of the reduced system efficiency when solar carries a large fraction of the heating load, i.e., a great deal of useful collected heat is wasted in overheating.

In general, the results of the commercial systems clearly show the potential technical and economic feasibility for well engineered and properly installed systems.

PERFORMANCE RESULTS--PASSIVE SYSTEMS

Table 6 lists the results of three of the passive solar systems reported on. While the solar efficiencies appeared high, the extreme excursions of temperature raise serious questions as to the feasibility of the systems. Temperatures as low as 46°F clearly indicate failure of the system to heat. In the second installation, the results reflect operation only in March and April, which is scarcely a test at all. Interior temperatures as low as 62°F in the spring season suggest that mid-winter conditions would be unacceptable.

Table 6

PASSIVE SOLAR SYSTEMS RESULTS

Installation	Collector Efficiency (%)	System Efficiency (%)	Room Temperature Range (°F)	Reference Author/Installation
	48.7	43.2	46 to 100	Freeborne [1]/ Residence
2	43.8	43.1	62 to 84	Freeborne [1]/ Residence
3	45.0	45.0	62 to 81	Weston [24]/ Warehouse

Clearly the reported efficiencies would also be severely degraded if the thermal storage uncontrolled heat delivery to load is related to the high

temperatures experienced. It appears reasonable that solar storage efficiencies must relate to passive as well as active systems.

In addition to the reports by Freeborne [1] and Weston [24], Boleyn [25] has reported solar gains (passive heating) by large south facing windows in two different homes of 15% to 30%. However, such figures are misleading because the overnight thermal losses have not been accounted for. Just as active solar collectors have heat loss terms as well as incident radiation absorbed terms, one should also consider the thermal losses from passive solar collection and storage devices.

PERFORMANCE RESULTS--CONCLUSIONS

The majority of solar heating and cooling systems reported on at the Broadmoor Conference failed to meet predicted levels of performance. Many systems, in fact, did not even approach the expected or designed level of performance. The difficulties encountered fell into two major categories. The first was that the presently accepted equations governing the performance of solar heating and cooling systems were based primarily on the solar collectors and did not adequately reflect the performance of the integrated solar system. Fortunately, it is now clear, in principle, what additional calculations are necessary to accurately describe the predicted performance of a solar system design.

Many of the present design tools currently used (primarily in the residential area) do not consider the effects on system performance of:

- Collector modules in series flow configurations when incorporated into collector arrays;
- Heat losses from interconnections between modules and manifolding of module pairs (or triplets) in parallel flow arrangements;
- Heat losses from
  - Thermal storage units,
  - Piping and/or ducting (including the physical leakage of the heat transfer fluid--primarily air), and
  - Other solar components (heat exchangers, pumps and blowers, exposed valves, etc.);
- Variations in control strategies due to design and/or faulty operation; and
- Parasitic electrical power requirements of the solar system.

The effect of two collector modules in a series flow configuration and heat losses from the connection between modules may reduce the actual useful predicted heat collection to 60% to 98% of the useful solar energy collected. Thermal storage and piping/ducting heat losses have been detailed above.

Control strategy variations were discussed by Ward [26], where an error of 5°F on the control instrumentation temperature differential between the collector and storage, was shown to reduce the system efficiency by 8% to 12% of the collector output. Finally, the feasibility of solar systems requires high system COPs, as previously discussed.

The second area of difficulties causing reduced solar system efficiencies was in the installation and operation of the solar equipment. Primarily this involved a lack of recognition by both the installers (e.g., the heating contractors) and the designers of the importance of specifying and incorporating such essential items as adequate insulation and proper control strategies. Again, this second difficulty is correctable, based on what has been learned at the Colorado Springs conference. Hardware errors involved in the installation, operations, and maintenance areas included: controls (poor designs and/or malfunctions), inadequate insulation, excessive complexity of system design and/or operation, and a severe lack of diagnostic tools.

Bartlett [27] has classified the control problems into three groups: (1) control sensor problems, (2) problems with controllers, and (3) problems with control actuating devices. Control sensors have been inadequately placed in the system (and thus do not reflect the actual operating condition of the system), have failed in use, and have provided inaccurate information; all resulting in extraneous or nonexistent energy flows. Controller problems have malfunctions of equipment as well as incompatibilities with solar system designs. Control actuating device problems include component failure and inadequate operation (e.g., valves or dampers do not fully close). Leaky dampers, for example, experienced leaks of 12% to 40% of full flow.

Inadequate insulation has been a major cause of problems and results from a lack of proper specifications or careless installation. In addition, thermal storage units typically have R-valves considerably lower than predicted (based on the applied insulation R-valves). For example, storage units have commonly had heat losses which exceeded predictions by 50% to 300%.

Excessive complexity of system design and/or operation has resulted in poor installations by inadequately trained personnel. It is noteworthy that commercially viable solar systems in Australia, Israel, and Japan (Japan has over two million solar DHW systems in operation at present) are all relatively simple in concept. This does not imply that the inherent simplicity of operable systems allows anyone to design and install a highly efficient system. Mistakes may be tolerated in the design of conventional systems utilizing powerful, concentrated energy forms; but the low intensity and intermittent characteristics of sunshine demand exceptional skill for its effective application.

The severe lack of diagnostic tools (e.g., the inability to quickly insert temporary sensors into each collector module to check for proper flow distribution) has hampered operational check-outs and maintenance efforts. True Testing, Balancing and Adjusting (TBA) is an essential requirement in any good HVAC system.

DESIGN, INSTALLATION, OPERATION, AND MAINTENANCE PROCEDURES

Problems in design methodology have included:

- Use of inadequate Rule-of-Thumb methods;
- Inability to estimate space heating and/or cooling loads to within accuracies of 10% to 25%;
- Lack of accurate input data, especially weather and solar radiation data (which may be off by 5% to 30%); and
- Limitations in solar calculations.

The limitations in solar calculations result in overestimates of "Solar Energy Used," exaggerated collector array efficiencies, incorrect use of f-chart or similar computer-derived models, lack of ability to properly size heat exchangers, pumps, etc., and a lack of design tools for hybrid systems (active/passive, solar with heat pumps, etc.).

Collector subsystem design problems may be classified as (a) materials related, (b) flow related, or (c) other. Materials related problems include glass-, plastic-, and fiberglass-reinforced cover plates, black paint and selective surfaces on absorber plates, absorber plate base materials, heat transfer fluids, internal piping material in collectors, outgassing, and sealants. Flow related problems include flow obstruction, flow distribution, poor internal pipe configuration, defective drainage, air leaks, and improper venting.

Storage design problems include excessive heat losses, lack of anticipated temperature stratification due to improper inlet and outlet connections, excessive space taken by storage, inadequate allowance for thermal expansion, leaks, corrosion, poor flow distribution through storage (usually pebble-bed storage units), and excessive pressure drops.

Other system design problems have included improper heat exchanger, pump, and/or blower selection and design, inadequate piping and ducting design, and leaky valves/dampers. Considerable information on detailed problems has been presented at the conference and should provide considerable assistance in future designs. (See e.g., Sparkes et al. [28]). In addition to design considerations, the conference papers (Sparkes et al. [29] and others) have also detailed specific problems (and usually, the corresponding solutions) arising in the installation, operation, and maintenance of solar heating and cooling systems.

Collector array associated problems include: mounting collectors too close to the existing roof and improper flashing (causing rotting of wood structure and leaks), requirements of support structures to obtain greater collector tilts, wind and snow loading, insufficient space for thermal expansion, lack of attention to aesthetics, and poorly designed mounting brackets. Collector piping and/or ducting have required resoldering and recaulking to reduce or stop leakage of the collector fluid, and on-site connections of plumbing and

ducting has caused many delays. There has been significant glass breakage in handling; glued-on covers for protection of glazings during shipping have become brittle in cold weather and/or have melted in hot weather and became very difficult to remove; and air or vapor locks have occurred frequently in the collector loop because of improper filling operations and/or a lack of proper air vents. Many systems lack a proper fill mechanism and an ability to easily drain the collector for maintenance, and installation problems have arisen in joining together collector modules. Other findings include (Thayer et al. [30]):

- The lifting of collectors onto the roofs of buildings by means of a light duty cherry picker type boom crane is more cost-effective than using either manual lifting or a heavy duty construction crane.

- Installations where collectors were lifted to the roof manually were generally of poorer workmanship with higher potential for system leaks than installations where collectors were lifted by means of a crane. (The lifting of 140 to 160 pound collectors on a pitched roof on a hot day is extremely physically fatiguing with the result that the installation crew adopts a "devil may care" attitude.)

- A few firms in a geographical area will, in the future, specialize in the installation of collectors because they will possess the specialized experience and equipment necessary to win competitive bids for installations.

- The installation costs of collectors would be reduced and system reliability would be improved if collectors were built in lengths longer than eight feet since most arrays are taller than eight feet. (The present length seems to be dictated by the manual handling methods.)

- Manufacturers do not comprehend the abuse to which their collectors are subjected on the job site before and during installation. Collectors are walked upon, twisted, exposed to high temperatures, dust storms, and pipe fittings are over torqued beyond the point of failure. Warnings and notices in the installations manual are ineffective because they are generally not read.

- The installation times of internally manifolded air collectors are lower than externally manifolded collectors where individual ducts must be built and connected. The fabrication costs of internally and externally manifolded collectors should be about identical.

- Starter strips used by installers to align the rows of collectors are often badly warped 2-inch by 4-inch lumber. The result is poor alignment of the collectors with gaps beyond the correction capacity of gaskets and pipe unions. System leaks and poor visual appearance are a consequence.

- The cost of installation will be highly dependent upon the crew size because the crews adjust the speed and effort on normal residential installations in such a way that the job takes one full day.

- Poor alignment of collectors with potential system leaks occur when care is not taken to maintain a precise centerline for the roof trusses.

- Panels delivered to the work site have on occasion been loaded in enclosed trailers by forklifts at the warehouse. To remove the panels from the trailer, workers have been forced in some cases to tear apart the packing in place and pull out the panels one by one.

- During installation on sunny days, exposed panels reach stagnation temperatures at the absorber. Hot panel in such cases can be handled with gloves only and heat escaping from panels makes working around the array uncomfortable. Glare from exposed glazing also reduces workers' efficiency.

Storage installation problems include the fact that both water tank storage and pebble bed storage require a great deal of space, and that the installation must provide access for maintenance and repair. Underground storage have in general failed to meet expectations because of excessive thermal losses due to moistened or nonexistent insulation, degradation by soil, and ground water drainage. High water tables have also resulted in major damage to buried storage subsystems. Concrete water storage tanks have had structural failures and excessive leakage. Pebble bed storage units have had excessive dirt included in the rock, causing portions of the bed to be useless for heat transfer to and from storage and poor flow distribution through other parts of the pebble bed. Insulation has generally been insufficient and inadequately installed (particularly along the bottom of water storage tanks--resulting in excessive heat losses to the ground).

Distribution system problems include freezing of pipes, lack of pipe hangers and supports, lack of expansion compensators and efforts to minimize mechanical stresses from thermal expansion and contraction, lack of pressure tests, check valves installed backwards, leakage of 3-way valves, rust from the storage tank clogging a valve, pumps installed improperly (mechanically and electrically), and improper or nonexistent provision for draining relief valves. Duct installations require a relatively larger space, requiring more careful design and use of space during installation. In addition, conflicts between plumbing, ducting, and electrical wiring rough-ins have occurred over the best use of space. Dampers have been installed improperly, backwards, and in the wrong location. Fans have operated noisily due to undersizing of ducts. Freezing of DHW piping/exchangers have occurred in air systems as well as water systems.

Chopra et al. [31] evaluated 47 operating solar demonstration sites and found that freezing occurred in 30% of these sites. Eight of 16 water systems froze, 2 of 19 water-glycol systems experienced freezing problems, and 1/3 of the monitored air systems with a DHW option had freezing incidents. Figure 1 [31] presents a composite picture of the reasons why some of the current generation of solar systems experienced freezing. Chopra et al. [31] and Sidles et al. [32] have provided an excellent compendium of recommendations for avoiding future freezing incidents.

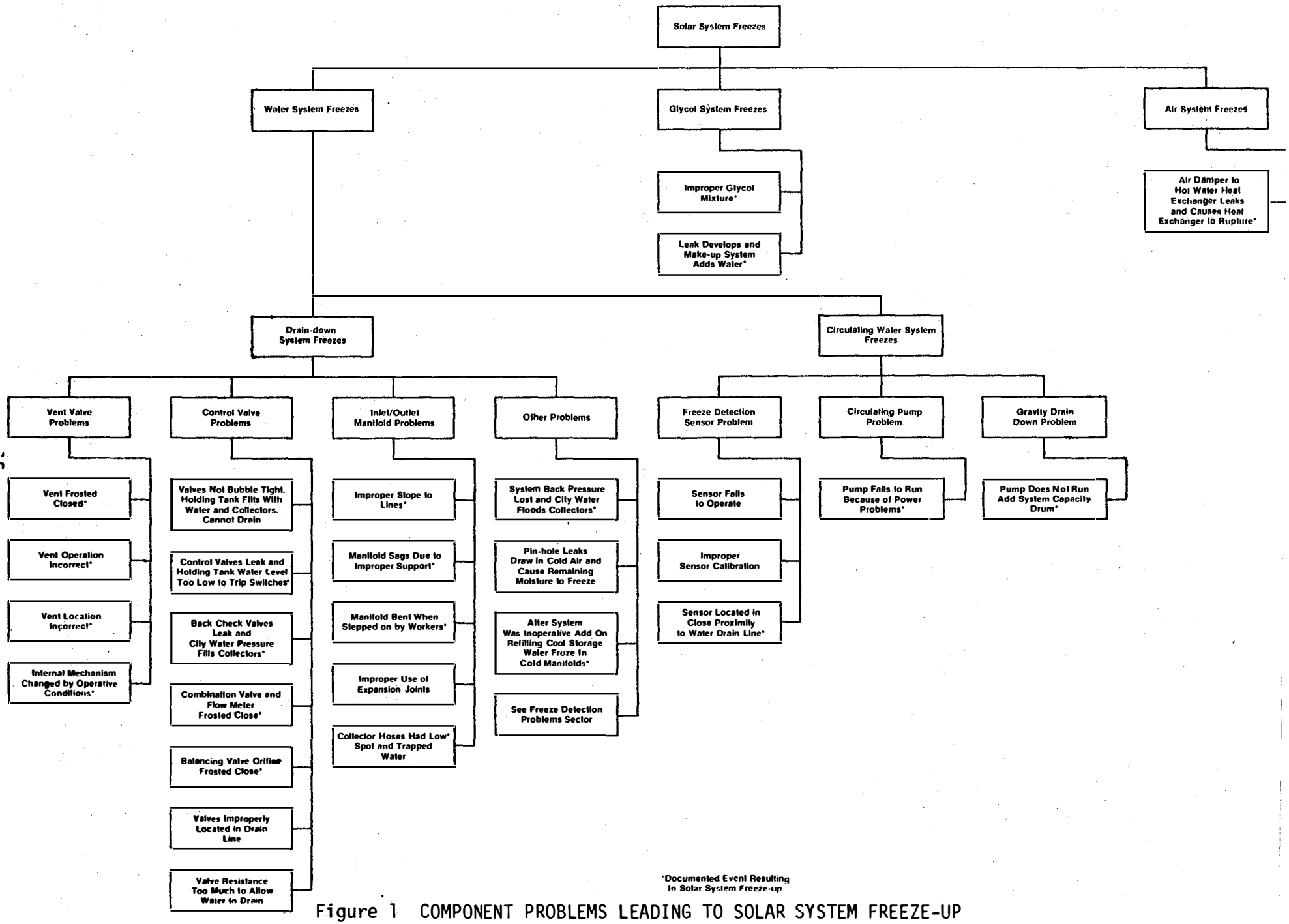

Figure 1 COMPONENT PROBLEMS LEADING TO SOLAR SYSTEM FREEZE-UP

Control system problems have included faulty wiring, faulty switches, inoperative sensors, and sensors improperly located. A major difficulty has been the inability to service prewired circuit boards in the field. Passive systems have had problems of overheating, excessive glare, and fading of interior decorative colors. Water walls have had serious leakage and maintenance problems.

Manufacturers guidelines for mechanical room layouts have been sketchy or nonexistent with the result that expensive trial and error designs are tried on the job site. It is common particularly in air systems to have conflicting uses of space for electrical, domestic plumbing, and solar energy transport. Bids for solar installations often contain excessive contingency allowances. (One installation contractor commented that actual costs were less than one-half his bid) [30].

Among the lessons learned about solar systems, one of the main ones is the importance of maintenance of a solar system. Some of the maintenance questions that are important to attend to are the following [29]:

- The air filters located on the fan-coil units and in the ducts should be checked once a month. They should be replaced as necessary, which would be at least once a year, and sometimes twice a year.

- The dampers should be checked regularly and adjusted to ensure proper closure. They should be oiled occasionally as needed.

- Motors should be checked for wear regularly.

- Blower bearings and motors in the air-handling units should be checked periodically.

- The collector seals should be checked a few times a year, and should be resealed when necessary.

- In the event of a power failure, or freezing weather, special care should be taken to insure against freezing of pipes and components.

- Pipe joints and bands should be inspected regularly for signs of leakage, or of stress that may lead to leakage.

- Special attention should be paid to roof leakage and deterioration.

- Pipe insulation should be inspected periodically for degradation.

Routine maintenance is seen by some system owners as being more complicated and more frequent than with a conventional heating system. Several users of solar systems have pointed out that a detailed maintenance manual would be of great help to them. Most installers do not supply the owner with such a manual. Sparkes et al. [29] concluded that:

"The different kinds of problems that arise in building construction, and in heating, cooling and domestic hot water systems in residential buildings also show up in buildings with solar systems. There are also additional problems in installation, operation, and maintenance that are special to solar systems. Many of these are problems that came up after the systems were installed, and had not been anticipated earlier. These problems and the solutions that are being tried out are providing a large body of experience, which can be made use of in making future solar installations more efficient and reliable."

Cash [33], in discussing solar hardware problems, has made the statement that, "The lack of knowledge of what is required in solar hardware has resulted in many unnecessary mistakes being made in the design, production, and installation of solar heating and cooling systems." In addition, "Some means must be provided to ensure that the system is performing properly, since improper performance of the system is one of the most difficult problems to detect."

COSTS AND BENEFITS

Several papers were presented at the conference which discussed costs and benefits of solar heating and cooling systems. Remmers et al. [34] reported on six of ten HUD-funded demonstration retrofit, space and DHW heating systems. A review of the HUD test program indicates that:

- The liquid-heating systems were easier to install than the air-heating collector systems;
- Significant installation and operational problems have affected the performance of all six systems (see Table 7);
- The liquid DHW system has demonstrated the best performance for DHW heating; the other systems have not proven cost effective; and
- Maintenance contracts appear to be a necessary part of any solar installation made in public housing.

Table 8 provides a summary of these HUD systems.

These apparently discouraging results are contradicted by DeLima et al. [35] who reported on the costs of nonfederally funded residential installations. According to DeLima, as of March 1978, the total number of residential SHAC installations throughout the country, excluding swimming pool installations, have been estimated by Booz, Allen, and Hamilton to be in the range of from 55,000 to 60,000. This estimate is based on data obtained from collector manufacturers, DOE's Energy Information Administration and six SMSAs scaled to the U.S. population. The installation count, less pool systems, by SMSA, was found to be:

Table 7

SOLAR SYSTEM INSTALLATION AND OPERATIONAL PROBLEMS [34]

House No.	Type of Solar System	Installation and Operational Problems
1	Liquid SAHP	o Refrigerant leak--caused compressor to overheat and degraded heat pump performance. o Tenant complained of insufficient DHW at times when the back-up natural gas was shut off.
2	Backyard Solar Furnace	o Installation delayed by manufacturer's inability to meet delivery schedule. o Broken collector cover glass (inner pane) due to excessive thermal stress. o Damper motor stuck on--consumed additional parasitic electrical power, permitted thermosiphoning to occur, and finally caused damper motor to fail.
3	Liquid DHW	o Moisture from snow melt leaked into two of the collector panels and contaminated the collector insulation and produced condensation on the inside of the cover glasses. o Broken electrical wire between the controller and circulating pump shut down the pump and caused the collector fluid loop to boil over. o System vapor locked resulting in "no flow" condition and subsequent system boil over.
4	Air w/o Storage	o Installation hampered by requirement to construct a carport on which the collectors are mounted. o Very poor DHW heating performance
7	Air DHW	o Numerous installation problems including: - inability of manufacturer to deliver hardware - coordination problems with subcontract labor - failure to pass building department inspection o Loose blower pulley resulting in curtailed operation on several occasions.
10	Air w/Eutectic Salt Storage	o Installation problems similar to those experienced with House 7. o Excessive uncontrolled distribution causing the house to be uncomfortably warm during the summer. o Damper motor failure resulting from poor installation--sealant used on connecting ductwork interfered with the operation of the damper. o Very poor DHW heating performance

Table 8

HUD TEST PROGRAM RETROFIT SOLAR SYSTEM DESIGN SUMMARY [34]

House No.	Solar System Description	Manufacturer (Installer)	Installed Price*	Predicted Annual Solar Contribution	Predicted Cost Benefit: Payback Period	Predicted Cost Benefit: Rate of Return	$/ft^2
1	Space Heating & DHW--liquid SAHP system utilizing a 1 hp heat pump, 2 unglazed ground-mounted collectors (64 ft^2), an 80 gal DHW heater (no preheat tank) and a load shedding controller	General Solar Corp. (F & N Construction)	$5300	71%	18 yr	7%	83.8
2	Space Heating Only--backyard solar furnace (128 ft^2 of collectors and 12 yd^3 of rock storage) operated in tandem with house furnace	Future Systems Inc. (Sun-Trac of Denver)	5847	57	18	5	45.7
3	DHW Only--closed-loop liquid system utilizing 3 roof-mounted, selective surface collectors (61.5 ft^2) and an 82 gal preheat tank	American Heliothermal Corp. (Solar Industries Inc.)	2464	61	16	7	40.1
4	Space Heating & DHW w/o Storage--air system utilizing 6 vertical wall-mounted single-glazed fiberglass collectors (120 ft^2) and an 82 gal preheat tank	Devair Systems	2927	21	18	6	24.4
7	DHW Only--air system utilizing 3 roof-mounted double-glazed collectors (58.5 ft^2) and an 82 gal preheat tank	Solar, Inc. (Mountain Mechanical Sales, Inc.)	2640	52	18	5	45.1
10	Space Heating & DHW--air system utilizing 14 vertical wall-mounted double-glazed collectors (205 ft^2), 75 ft^3 of eutectic salt storage and an 82 gal preheat tank	Solar, Inc. (Mountain Mechanical Sales, Inc.)	8930	48	20	2	119.1

*Includes the building permit fees which ranged between 2% and 2 1/2% of the installed price. The costs of the structural analyses that had to be performed to obtain the building permits are not included. These averaged about $200 per installation.

- Boston - 110
- Denver - 274
- Los Angeles - 643
- Phoenix - 682
- Washington, D.C. - 145

Solar energy applications appear to vary by region. Domestic hot water applications are predominant in Washington and Boston. In Washington they account for 55% of all the nonfederally funded installations but comprise only 18% of the installed collector area. In Boston they account for 65% of the installations but comprise only 13% of the installed collector area. Combined DHW space heating applications are predominant in Denver. They comprise 45% of all federally and nonfederally funded installations. The majority of installations in Phoenix and Los Angeles are swimming pool systems. They account for 50% and 83% of all installations in Phoenix and Los Angeles respectively.

The average total installed costs for nonfederally funded solar domestic hot water systems ranged from a low of $1,004 for Phoenix to a high of $2,085 for Boston, as shown in Table 9. The average unit cost ranged from a low of $28.90 for Phoenix to a high of $47.70 for Los Angeles per square foot of installed collector area, as shown in Fig. 2. If consumers used life cycle criteria for purchase decisions, solar domestic hot water systems will compete with energy sources which today cost between $6.80 and $15.00 per million Btu (assuming the alternative energy sources escalate at 8% per year).

The majority of collectors examined on field surveys were hydronic, had copper absorber plates and tubes, glass cover plates, and internal manifolds. Selective absorber plate coatings were used in 50% of the systems. Freeze protection was accomplished in the majority of the installations by the use of drain-down systems.

> ONLY MINOR PROBLEMS WERE ENCOUNTERED IN THE INSTALLATION AND THE OPERATION OF SYSTEMS VISITED. ONLY ONE OF THE 30 SYSTEMS EXAMINED HAD MAJOR DESIGN PROBLEMS. MOST SYSTEMS HAD MINOR INSTALLATION PROBLEMS SUCH AS LEAKING PIPES AND FAULTY CONTROLS. HOWEVER, INSTALLERS STOOD BEHIND THEIR WORK AND RECTIFIED ALL MALFUNCTIONS. AFTER INITIAL FIXES, SYSTEMS GENERALLY ARE WORKING WELL [35].

Costs of commercial (nonresidential) solar energy systems have been reported by King et al. [36] and are summarized in Table 10. It should be noted that the space cooling projects all employed concentrating or focusing collectors. King et al. [36] suggests that because of this, the costs cannot be compared directly with flat-plate collectors. However, in this reviewer's opinion, flat-plate collectors can perform as well as concentrators for space cooling applications; and therefore, on the basis of the presented data, it would appear that these concentrating collectors cannot be considered as economically viable at the present time in the cooling installations discussed.

Table 9

COST COMPARISON FOR DOMESTIC HOT WATER SYSTEMS [35]

SMSA	Average Size (Sq Ft)	Average Cost	Predicted % of Hot Water Load Supplied	MM Btu's Supplied Per Year By Solar	Equivalent kWh Supplied Per Year	Local Electricity Price (¢/kWh)	First Year Savings	Simple Payback (Years)	Equivalent Cost Including Fuel Price Escalation (¢/kWh)[1]
Boston	58	2,085	47	10.2	2975	5	$149	14	4.4
Washington	57	1,991	54	10.9	3200	5	$160	12	3.9
Denver	48	1,719	73	16.0	4684	4	$187	10	2.3
Phoenix	34	1,004	64	11.0	3225	4	$129	8	2.0
L.A.	34	1,600	51	9.8	2884	4	$115	14	3.5
Miami	37	1,239	58	9.3	2720	4	$109	12	2.9

[1]Assumes 20 year financial analysis and 8% escalation rate for competing fuels.

TABLE 10

COSTS OF COMMERCIAL SOLAR PROJECTS [derived from 36]

Project		Collector Array		Subsystem Support		Storage		Piping/ Ducting & Insulation		H & C Equip		Controls Electrical		Total Installed Cost
		($/ft^2)	(%)	($/ft^2)	(%)	($/ft^2)	(%)	($/ft^2)	(%)	($/ft^2)	(%)	($/ft^2)	(%)	($/ft^2)
Passive Window Wall		5.70	81.4	-	-	0.70	10.0	-	-	0.35	5.0	0.25	3.6	7.00
Process Hot Water	1.	9.90	41.2	7.10	30.0	2.00	8.2	3.10	12.8	-	-	1.90	7.8	24.00
	2.	17.20	40.0	7.70	17.9	2.50	5.8	12.80	29.8	-	-	2.80	6.5	43.00
	3.	11.50	41.1	2.80	10.0	2.30	8.2	10.20	36.4	-	-	1.20	4.3	28.00
Heating	1.	12.10	37.8	3.10	9.7	3.60	11.3	4.90	15.3	4.90	15.3	3.40	10.6	32.00
	2.	11.40	18.7	11.70	19.2	6.50	10.7	20.60	33.8	2.20	3.6	8.60	14.0	61.00
	3.	14.90	48.1	7.10	22.9	2.40	7.7	2.90	9.4	1.90	6.1	1.80	5.8	31.00
Heating & Cooling	1.	38.00	33.6	11.80	10.4	7.20	6.4	31.00	27.4	15.00	13.3	10.00	8.9	113.00
	2.	135.00	69.6	5.10	2.6	13.30	6.9	28.00	14.4	6.60	3.4	6.00	3.1	194.00
	3.	30.00	47.6	5.60	8.9	4.60	7.3	15.00	23.8	4.40	7.0	3.40	5.4	63.00

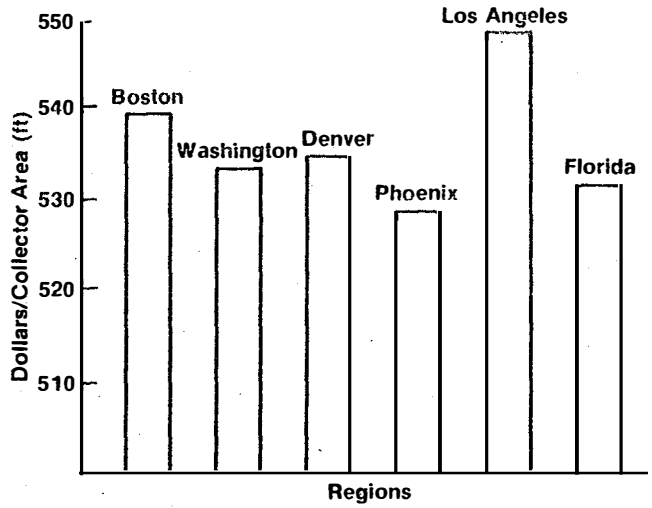

FIGURE 2

It is interesting to note the wide variations in as common a component as storage tanks. Table 11 compares storage costs which range from \$0.70 to \$13.30/ft^2. Steel water tanks alone ranged from \$0.70 to \$3.70/gal.

Table 11

STORAGE COSTS [36]

Project	Container	Capacity	Cost/Unit Volume	Cost/Unit Area
Passive				
Kalwall	Concrete slab, contents of warehouse	----	----	\$0.70/ft^2
Process Hot Water				
Iris Images	Three interior tanks, steel	360 gals	\$3.60/gal	\$2.00/ft^2
Hogate's	Two interior tanks, steel	10,000 gals	\$1.00/gal	\$2.50/ft^2
Aratex	Exterior tank, fiberglass	4,000 gals	\$3.00/gal	\$2.30/ft^2
Heating				
Moseley	Interior tank, steel	2,000 gals	\$0.70/gal	\$3.60/ft^2
Blakedale	Buried exterior tank, steel	5,000 gals	\$1.20/gal	\$6.50/ft^2
Scattergood	Partially buried pebble bed	65 tons	\$129/ton	\$2.40/ft^2
Heating and Cooling				
Radian	Exterior tank, fiberglass	1,500 gals	\$1.70/gal	\$7.40/ft^2
Reedy Creek	Two exterior tanks (hot and cold) steel	20,000 gals	\$2.60/gal	\$13.30/ft^2
Trinity	Two exterior buried tanks, steel	20,000 gals	\$3.70/gal	\$4.60/ft^2

Struss et al. [37] evaluated the economics of hotel/motel solar hot water projects and considered several possible, developing trends. These include:

- With the proper application a selective surface can be more cost-effective than a nonselective type collector.
- The larger the system, the less the cost per ft^2 of collector, and the less the total system unit cost.
- Projects are costing between $100/M BTU/yr and $200/M BTU/yr.
- Average design costs are 10% of total system cost.
- Wood support structures are $1.00/$ft^2$ of collector while other type structures are at least $2.00/$ft^2$.
- Liquid storage tank costs average $1.44/gal.
- Project material costs (excluding collectors) are averaging $6.16/$ft^2$ of collector.

Sedmak [38] has considered areas for potential cost reductions including: a need to size the solar systems in a cost-effective manner, and to use cost-effective materials and subsystems in designing the systems. Sedmak also considered the implications of basing solar investment decisions on life cycle cost comparisons. A noteworthy conclusion was that the energy cost rises dramatically when the system life is ten years or less, primarily because the cost of the system must be paid in a rather short period of time. Extension of system life beyond approximately 20 years has little effect on the first-year energy cost because the capital recovery factor is rather insensitive to mortgage terms greater than 20 years. (See Figure 3.)

Figure 4 depicts the sensitivity of the after tax cost of solar energy to system lifetime and interest rate for one system. Rather surprisingly, the after tax energy cost rises as system lifetime increases above approximately 10 to 15 years. This results because depreciation deductions decline at a faster rate than does the CRF. (CRF Capital Recovery Factor, "Mortgage Payment.")

Finally, Sedmak concludes that, "The cost of solar energy seems to be directly related to the complexity of the solar system" [38].

Sedmak [38] also contended that a life cycle cost analysis was a necessary but not sufficient condition for optimal investment in a solar system. Figure 5 compares the time of economic competitiveness for one system for both life cycle cost comparison and in addition, present cost comparison, i.e., the first-year solar energy costs.

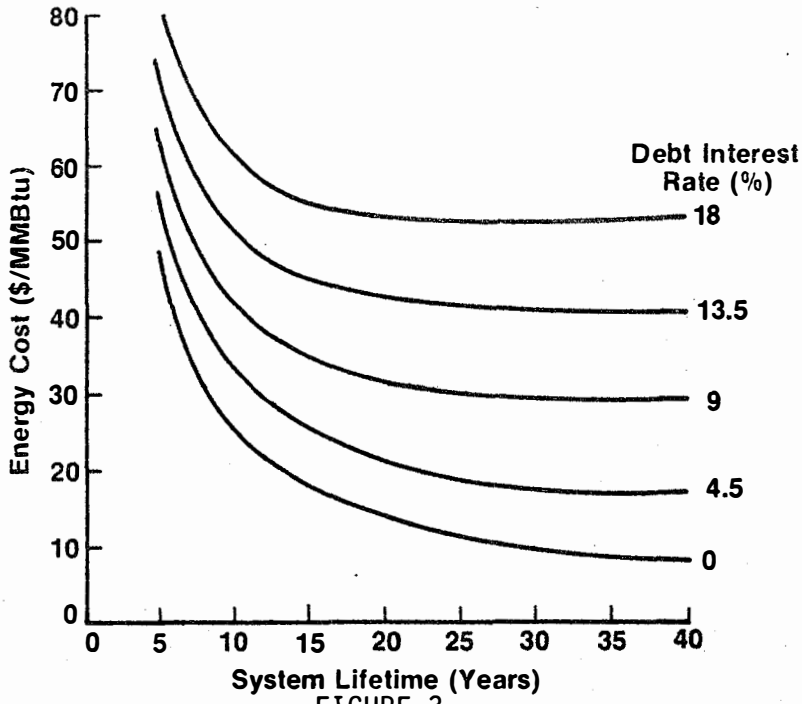

FIGURE 3

First Year Solar Energy Cost (Before Tax)

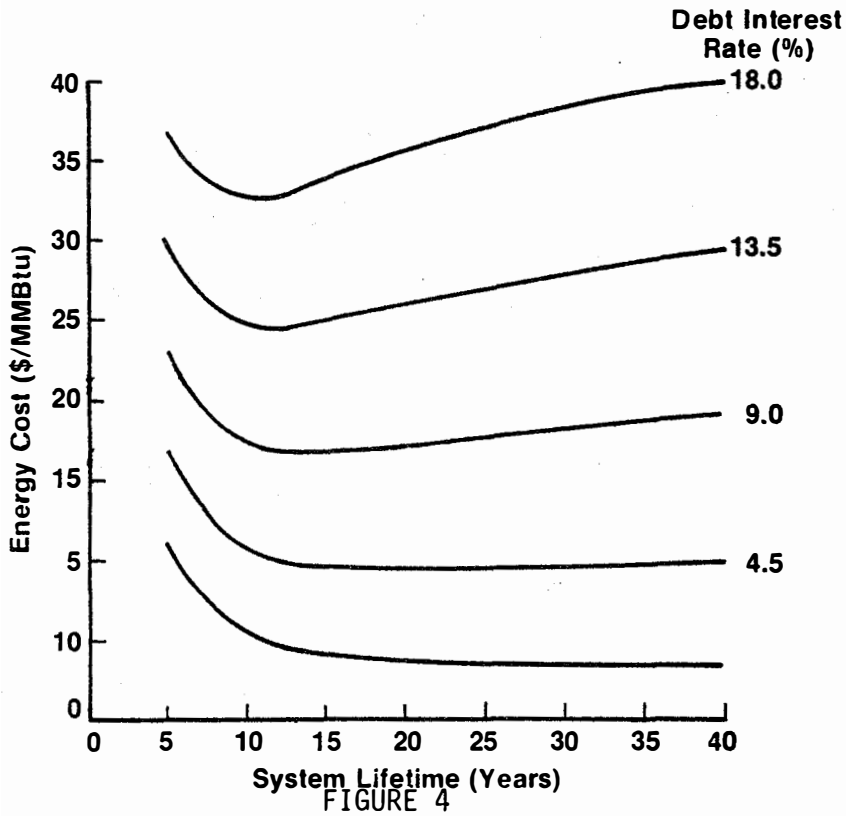

FIGURE 4

First Year Solar Energy Cost (After Tax)

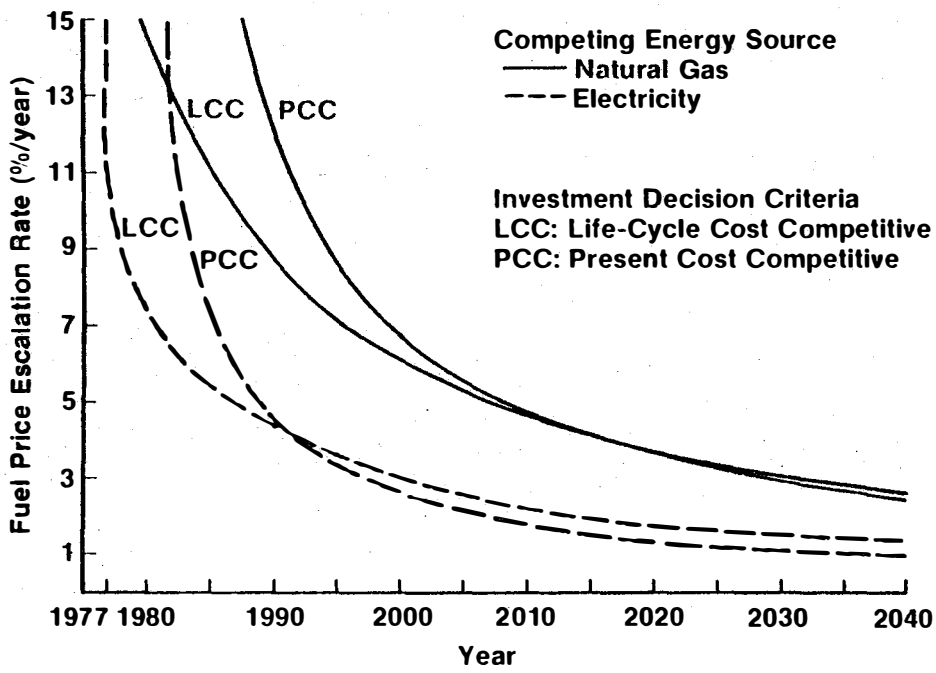

FIGURE 5

Time of Economic Competitiveness vs. Fuel Price Escalation Rate

RECOMMENDATIONS

Numerous recommendations for improvements in system performance, durability, and cost have been presented at the conference. Lof [39] has made several general comments, which are included here for emphasis:

> The Solar Heating and Cooling Demonstration Program was intended by Congress to show the American public, including architects, engineers, manufacturers, and contractors, that solar heating is ready for public use and can alleviate our serious energy shortage. To the extent that well-proven systems were selected and demonstrated, the program has been beneficial. However, many systems were selected and installed, at government expense, which had inferior characteristics, inadequate design, and totally unproven performance.
>
> To correct the mistakes of the past, and to establish solar energy use in our homes and businesses, I believe the following measures must be taken.
>
> (1) In the solar heating field, we must insist on high quality, capably installed, dependable, long-lived certified equipment. The marketplace will then weed out the inferior goods and practitioners. The demonstration programs of DOE, DOD, HUD, and other agencies must be based on selection of economical, proven systems, not the most innovative or speculative. Today, perhaps more than anything else, solar needs respectability and credibility among 200 million skeptics.
>
> (2) The desperate need for <u>data on cost and performance and reliability</u> of operating solar heating systems of all types must be filled by support of capable evaluation studies by experienced engineers in well-designed solar installations. Even among widely used systems, reliable operating data are scarce. The public must be provided assurance that solar can and will do the job.
>
> (3) We must do a far better job of <u>systems</u> engineering and integration. Most of the problems being reported at this meeting, and some of the total failures that aren't being reported, are due to a lack of understanding of this requirement. Even the <u>best</u> components, if poorly matched and incompetently assembled, will fail to provide satisfactory service.
>
> (4) <u>Improvements</u> in integrated solar heating systems are needed, so that good performance, both with respect to <u>heat delivery efficiency</u> and also with respect to <u>mechanical integrity, reliability, and durability</u>, can be achieved. Research is the lifeblood of a new industry, and with solar profits some years in the future, strong support of the research and development program in DOE is essential. These improvements require the skillful application of effort in a research and development environment--not in trial and error public demonstrations. Even though the aviation industry is over a half century old, government funding

of research on aircraft has been essential all through the years. Fortunately, the public is not forced, or even permitted, to travel in experimental aircraft.

(5) We must facilitate the training of practitioners in the heating, ventilating, and air conditioning industry, who are already specialists in heating and cooling systems, to qualify them as experts in solar system installation and servicing. Assurance of reliable, trouble-free, long-lived solar heating systems for the general public is impossible unless these training needs are met.

This conference is showing the absolute necessity of good design, engineering, and installation of well-integrated solar heating systems. There are integrated solar heating systems which are providing excellent service, and they are indeed ready for commercialization. And there are good solar components, such as collectors, storage units, controllers, and other elements which need systems integration and development for their effective application--a research and development requirement.

In an attempt to assess the results of the conference, meetings were held with selected participants at the end of each day of the conference. These participants included representatives from private industry (solar and otherwise), universities, nonprofit organizations, and government (DOE, HUD, etc.). Recommendations developed in these meetings have been reported by Bishop [40] and include:

- Initiate systems engineering and integration program to replace component/subsystem development. Do not continue collector, controls, and storage programs as separate elements; rather develop them in a systems concept.

- Emphasize field test program for well-engineered SHAC systems. Initiate a second generation "design-to-cost" competition to develop and test systems-engineered space heating/cooling systems. Guarantee a subsequent market for winners (e.g., demonstration program use).

- Develop diagnostic tools for installed system evaluation/optimization.

- Transfer "lessons-learned" to users--especially on DHW systems, need design, installation, check-out procedures. Long-term reliability still needs emphasis.

- Correct selected existing demonstrations to quantify potential gains in energy delivery, study system sensitivities, and fine tune systems.

- Start using seasonal COP to report system performance.

- Emphasize hybrid systems (passive and active).
- Initiate larger program in installation training.
- Emphasize modularization to reduce system costs/installation problems/costs.
- Instrument more passive homes.

Conference attendees provided additional information and recommendations. Among other valuable inputs by the conference attendees, paragraph 9 of Appendix A is particularly noteworthy. Attendees felt that the federal government had several important options in helping to increase the application of solar energy for heating and cooling of buildings. These included (in the order of the greatest percentage of attendees advocating a particular point of view):

1. (54.2%) Provide educational material to designers and installers,
2. (52.9%) Fund more research and development,
3. (47.1%) Provide educational material to consumers,
4. (43.5%) Subsidize consumers,
5. (25.8%) Fund more demonstration projects,
6. (19.6%) Subsidize solar industry, and
7. (15.0%) Other.

It is clear from these priorities that the conference attendees recognized the importance of education material to designers, installers, and to the consumer. In this respect the Operational Results Conference was an important avenue of providing realistic information on the results of operating solar systems.

It is also noteworthy that the conference attendees advocated continued funding for research and development. In many respects this interest may be based on the desire for additional educational information. Clearly the ability of any organization to provide educational materials is severely limited if research and development are not continued concurrently, so that a source of new and relevant information is constantly available.

In addition to continued research and development, it is also essential that continued output from the National Solar Data Program also be emphasized. Such data provides the critically necessary information base on which any educational or training program is dependent.

AN ESSENTIAL FUNCTION OF ANY FEDERAL OR STATE GOVERNMENT PROGRAM TO AID IN THE LARGE-SCALE APPLICATION OF SOLAR ENERGY IS THE MAKING AVAILABLE TO THE AMERICAN CONSUMER ACCURATE AND WELL-SUPPORTED INFORMATION. THIS INFORMATION IS OBTAINABLE ONLY FROM RESEARCH AND DEVELOPMENT EFFORTS AND FROM THE

OPERATING RESULTS AND DATA OF STATE-OF-THE-ART, COMMERCIAL SOLAR HEATING AND COOLING SYSTEMS. THIS IMPLIES A CRITICAL NEED FOR CONTINUATION OF THE DEPARTMENT OF ENERGY'S SOLAR HEATING AND COOLING RESEARCH AND DEVELOPMENT PROGRAM AND THE NATIONAL SOLAR DATA PROGRAM.

Note that such a recommendation does not imply a continuation of a large National Solar Heating and Cooling Demonstration Program. In fact, responses from conference attendees, listed above, indicated that fewer than one-half of the people recommending continued research and development and solar data collection, advocated the funding of more demonstration projects. In fact, a recommendation by only 25.8% of the conference attendees (of which 70% are professionally involved in solar energy) that the Demonstration Program continue is paramount to a recommendation of nonsupport for the program. It is apparent that the federal government's investment in "mortar, brick, and solar hardware" is of significantly less value than a well organized research and development and solar data collection effort. There is no justification for continued direct-subsidizing of the solar industry through the Demonstration Program (although consumer subsidizing through tax credits is still recommended by 43.5% of the conference attendees, and thus should continue).

ON THIS BASIS, THEREFORE, THIS REVIEWER STRONGLY RECOMMENDS CONTINUATION OF THE DEPARTMENT OF ENERGY'S SOLAR HEATING AND COOLING RESEARCH AND DEVELOPMENT PROGRAM AND IN ADDITION, THE DEPARTMENT OF ENERGY'S NATIONAL SOLAR DATA PROGRAM. THIS REVIEWER RECOMMENDS THAT THE NATIONAL SOLAR HEATING AND COOLING DEMONSTRATION PROGRAM BE DISCONTINUED, AND THAT FUNDS FOR THE DEMONSTRATION PROGRAM BE UTILIZED IN THE R&D AND SOLAR DATA PROGRAMS. IT IS APPARENT THAT THOSE FUNDS BUDGETED FOR THE NATIONAL SOLAR DEMONSTRATION PROGRAM CAN BE UTILIZED MUCH MORE EFFECTIVELY IN PROVIDING RESEARCH AND DEVELOPMENT AND SOLAR DATA FOR AN INFORMATION BASE, WHICH CAN THEN BE INCORPORATED IN EDUCATIONAL MATERIALS FOR THE AMERICAN PUBLIC AND THEIR USE OF SOLAR ENERGY.

CONCLUSIONS

In summarizing the conference, one very definite conclusion which can be drawn is that solar heating and cooling systems are technically and economically feasible at the present time. If this conclusion seems contradictory, it is because a careful analysis of the results indicates rather precisely why the operational results of many of the solar heating and cooling systems presented at this conference failed to meet expectations. More importantly, it has now become clear what steps are necessary to ensure high quality systems in the future. The only necessity, as so graphically brought out by the conference, is that the solar system must be engineered and installed properly.

An even more important result, which virtually transcends the original intended purpose of the conference, is the demonstrated importance of systems. Not only do the conference results provide a clear indicator of solar heating and cooling feasibility, but they also can be readily transferred to conventional heating and cooling systems.

For years conventional furnaces have been oversized to account for poorly designed or carelessly installed conventional heating systems. Great care and considerable effort have gone into the research and development of fuel-fired furnaces, with special efforts exerted in order to ensure the highest efficiencies and cost effectiveness. Precise standards as to the testing and expected performance have been carefully developed by such organizations as ASTM, ASHRAE, and others. No effort has been spared by industry and others to ensure the best possible products consistent with economic constraints. And once this product, in our case a heating furnace, has been brought to near perfection, it has been turned over to a residential installer who oversizes the unit by 200% to 300% in order to account for leaky ducts, inadequate controls, and poorly designed systems. There has in fact been no systems engineering applied to heating and cooling systems.

It should not be a great surprise to realize that the solar industry has fallen into the same trap. In their case the "furnace" is the solar collector, and a great deal of effort has gone into the design, testing, and establishment of standards for solar collectors. But then they were attached to the other components of the solar system and the performance was unexpectedly reduced. Unfortunately, it is not economically feasible to oversize solar collector arrays to account for system defects, just as it is no longer economically feasible to operate oversized conventional furnaces at dismal efficiencies, when the cost of conventional fuels continue to increase rapidly.

This nation is suddenly faced with the necessity of developing heating and cooling systems. This is something which has never been done before. In the past we have always developed components and then tied them together in what can only be described as a haphazard way. The space program demonstrated the need for systems analysis if reliability was to be more than a chance probability. But the space program systems were heavily engineered and limited to a small number of any one system.

Solar systems, on the other hand, must be mass-produced, and inevitably mass-marketed. Standards must be developed for systems, not just components. It is particularly noteworthy that, until solar heating systems were considered, no organization had ever developed any system standards! And just as there has been a complete lack of standards for systems, there has also been little development of complete systems by manufacturers of solar collectors, controls instrumentation, pumps and blowers, and so forth. It is clear that research and development must be continued by the government in the area of solar heating and cooling systems if there are to be significant advances in the design and installation procedures of complete systems. Industry left to itself cannot realistically be expected to provide the critically needed effort in systems. Additionally, data from operating solar systems must continue to be collected if the consumer and solar industry are to be kept reasonably informed on the technical and economic viability of solar heating and cooling systems.

It is perhaps true that solar domestic hot water heating systems do not require further governmental research and development funding because the solar industry is now selling complete solar DHW systems. In addition, solar space heating systems which are technically and economically feasible are

available now. However, the greater complexity of these latter space heating systems will require a continuing R&D effort by the government if major questions of design and installation are to be objectively resolved. While many now believe that solar space cooling using absorption chillers is also definitely a viable alternative, it too will require further DOE sponsored R&D in order to advance this important area of solar applications.

In summary, the DOE-sponsored conference on Solar Heating and Cooling Systems Operational Results has demonstrated the overriding importance of systems engineering and installation, and clearly indicated the importance of systems development. It is now time to take advantage of the lessons learned.

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(All references are to the proceedings of the Solar Heating and Cooling Systems Operational Results Conference, Broadmoor Hotel, Colorado Springs, Colorado, November 1978; unless otherwise specified and denoted by a *.)

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5. Lee, T. D., "Thermal Performance Evaluation of the Florida Gas Company Solar Energy System" Session II.

6. Hancock, O. G., Jr. "Solar Cooling of a Florida Residence" Session II.

7. McCumber, W. H., Jr. "Comparison of Actual Collector Array Performance with Predicted Performance" Session VII.

8. Ward, J. C. "Electricity and Gas Consumption of 24 Solar Homes Compared with 26 Conventional Homes Having Identical Heating Loads" Session VII.

9. Karaki, S. "Solar Air-Heating and Heat Pump Cooling in CSU Solar House II (1977-1978)" Session II.

10. Hedstrom, J. C., Moore, S. W., Balcomb, J. D. "Performance of Los Alamos Solar Mobile/Modular Home Unit #1" Session II.

11. Leverenz, D. J.; Joncich, D. M. "The Performance of a Residential Scale Solar Heating System" Session II.

12. Erdmann, D. R.; Persons, R. W. "The Arlington Solar House of the University of Wisconsin--Madison" Session II.

13. Bedinger, A. F. G.; Bailey, J. F. "Performance Results and Operating Experience of the UT-TVA Solar House (1976-1978)," Session II.

14. Ward, D. S.; Ward, J. C.; Oberoi, H. S. "Solar Cooling Performance in CSU Solar House III" Session II.

15. Wallace, C. T. "Thermal Performance Evaluation of the Reedy Creek Utilities Solar Energy System" Session III.

16. Hedstrom, J. C.; Murray, H. S.; Balcomb, J. D. "Solar Heating and Cooling Results for the Los Alamos Study Center" Session III.

17. Jensen, R. N. "The Langley Systems Engineering Building; Solar Cooling and Heating Experience and Performance" Session III.

18. Aquila, V. S. "Thermal Performance Evaluation of the Hogate's Restaurant Solar Energy Hot Water System" Session III.

19. Bartlett, J. C. "Comparative Evaluation of the Thermal Performance of Solar Energy Systems" Session VII.

20. Armstrong, H. L. "Thermal Performance Evaluation of the Aratex Services, Inc., Solar Energy Hot Water System" Session III.

21. Crum, J. W. "Performance Evaluation of the Trinity University Solar Energy System" Session III.

22. Murray, H. S.; Hedstrom, J. C.; Balcomb, J. D. "Solar Heating Results for the Nambe Community Center" Session III.

23. Fenton, D.; LaPlante, D.; San Martin, R. L.; Diamond, S.; Packard, C.; Shaw, H.; Stevens, W. "Performance and Operating Experience for the New Mexico Department of Agriculture Solar Heated and Cooled Building" Session III.

24. Weston, M. W. "Thermal Performance of the Kalwall Corporation Warehouse Passive Solar Space Heating System" Session III.

25. Boleyn, D. R. "Operating Results from Solar Homes in the Pacific Northwest" Session VII.

26. Ward, D. S. "Utilization of Operational Results" Session I.

27. Bartlett, J. C. "Evaluation of Solar Energy Control Systems" Session VII.

28. Sparkes, H. R. Raman, K. "Lessons Learned on Solar System Design Problems from the HUD Solar Residential Demonstration Program" Session IV.

29. Sparkes, H. R.; Raman K. "Lessons Learned on Solar System Installation, Operation, and Maintenance Problems from the HUD Solar Residential Demonstration Program" Session V.

30. Thayer, S. B.; Weaver, N.; Jacobs, P. "Cost-Effective Ways to Improve the Fabrication and Installation of Solar Heating and Cooling Systems for Residences" Session IV.

31. Chopra, P. S.; Wolosewicz, R. M. "Freezing Problems in Operational Solar Demonstration Sites" Session V.

32. Sidles, P. H.; Struss, R. G.; Brohl, E. C. "Operational Experience with Drain-Down Solar Systems" Session V.

33. Cash, M. "Hardware Problems Affect the Performance of Solar Heating and Cooling Systems" Session IV.

34. Remmers, H. E.; Tonelli, A. L. "Operation of Six Different Solar Retrofit Systems in Single Family Residences" Session VII.

35. Delima, H.; Hirshberg, A.; Dick, C. "A National Solar Heating and Cooling Evaluation System" Session VI.

36. King, T. A.; Moore, J. S.; Hale, H. J. "An Analysis of the Construction Cost of Ten Non-Residential Solar Energy Systems" Session VI.

37. Struss, R. G.; Brohl, E. C.; Sidles, P. H. "Evaluation of Economics of Hotel/Motel Solar Hot Water Projects" Session VI.

38. Sedmak, M. R. "An Analysis of the Actual Cost of Energy Generated by Solar Systems" Session VI.

39. Lof, G. O. G. "Solar Heating--Catch 22?" Luncheon Speaker.

*40. Bishop, C. J. Private Communication.

Appendix A

INFORMATION SHEET ON CONFERENCE ATTENDEES

STATES REPRESENTED AND NUMBER OF ATTENDEES
(317 Responses Out of 498 Registrants)

State	Number	State	Number	State	Number	State	Number
AL	10	IA	4	NE	5	SC	3
AZ	7	KS	10	NV	3	SD	1
CA	28	KY	3	NH	2	TN	5
CO	85	LA	2	NJ	5	TX	14
CT	4	MD	8	NM	7	UT	1
DC	16	MA	4	NY	9	VT	2
FL	4	MI	4	NC	1	VA	12
ID	3	MN	5	OH	3	WA	7
IL	10	MO	4	OK	3	WV	2
IN	1	MT	1	OR	4	WI	5
				PA	8	WY	2

1. Number of attendees affiliated with: (323 responses)

[] federal government	77	23.8%
[] state government	34	10.5%
[] local government	7	2.2%
[] private sector	174	53.9%
[] other	57	17.6%

2. Current professional activity of attendees: (373 responses)

[] architect	34	10.5%
[] engineer-design	84	26.0%
[] engineer-analysis	88	27.2%
[] program management	64	19.8%
[] construction	41	12.7%
[] solar equipment sales	20	6.2%
[] solar equipment manufacturer	19	5.9%
[] educator	40	12.4%
[] other	65	20.1%

3. Areas of formal training of attendees: (315 responses)

[] architecture	52	16.5%
[] engineering	207	65.7%
[] physics	39	12.4%
[] business administration	42	13.3%
[] building construction	44	14.0%
[] construction trade	30	9.5%
[] other	43	13.7%

4. Attendees professional involvement in solar energy: (328 responses)

[] no professional involvement	44	13.4%
[] less than one year	56	17.1%
[] more than one year	228	69.5%

Average number of years is 3.2 years.

5. Attendees opinions on the future of solar heating and cooling: (323 responses)

[] very promising	217	67.2%
[] uncertain	103	31.9%
[] no promise	4	1.2%

6. Solar applications which attendees feel are technically feasible at the present time: (323 responses)

[] domestic hot water	311	96.3%
[] space heating	275	85.1%
[] space cooling	97	30.0%
[] industrial process heat	183	56.7%
[] pool heating	274	84.8%
[] none of the above	6	1.9%

7. Solar applications which attendees feel are economically attractive at the present time for each different geographical region: (290 responses)

Application	Geographical Region: North-west	North-central	North-east	South-west	South-central	South-east	Total
Domestic hot water	145 / 50.0%	185 / 63.8%	207 / 71.4%	246 / 84.8%	220 / 75.9%	217 / 74.8%	272 / 93.8%
Space heating	64 / 22.1%	120 / 41.4%	131 / 45.2%	179 / 61.7%	135 / 46.6%	124 / 42.8%	232 / 80.0%
Space cooling	6 / 2.1%	5 / 1.7%	6 / 2.1%	72 / 24.8%	50 / 17.2%	45 / 15.5%	80 / 27.6%
Industrial process heat	45 / 15.5%	79 / 27.2%	74 / 25.5%	135 / 46.6%	114 / 39.3%	105 / 36.2%	149 / 51.4%
Pool heating	93 / 32.1%	113 / 39.0%	110 / 37.9%	236 / 81.4%	198 / 68.3%	199 / 68.6%	246 / 84.8%
None of the above	17 / 5.9%	4 / 1.4%	5 / 1.7%	3 / 1.0%	4 / 1.4%	3 / 1.0%	19 / 6.6%

8. Attendees feel that the major obstacles to solar heating and cooling applications and their corresponding priority are: (322 responses)

	Priority: 1	2	3	4 thru 7	Total
[] high initial cost	239 / 74.2%	38 / 11.8%	8 / 2.5%	1 / 0.3%	286 / 88.8%
[] inadequate financing available	22 / 6.8%	18 / 5.6%	10 / 3.1%	8 / 2.4%	58 / 18.0%
[] inadequate warranties available	21 / 6.5%	14 / 4.3%	12 / 3.7%	24 / 7.4%	71 / 22.0%
[] lack of product history	66 / 20.5%	51 / 15.8%	23 / 7.1%	13 / 4.0%	153 / 47.5%
[] lack of information for consumers	34 / 10.6%	25 / 7.8%	34 / 10.6%	13 / 4.0%	106 / 32.9%
[] technology not ready	31 / 9.6%	18 / 5.6%	11 / 3.4%	11 / 3.4%	71 / 22.0%
[] other	33 / 10.2%	7 / 2.2%	7 / 2.2%	3 / 0.9%	50 / 15.5%

9. Attendees feel that the federal government should increase the application of solar energy for heating and cooling by doing the following: (306 responses)

	Priority				
	1	2	3	4 thru 7	Total
[ ] fund more research and development	100 32.7%	33 10.8%	18 5.9%	11 3.6%	162 52.9%
[ ] fund more demonstration projects	20 6.5%	24 7.8%	21 6.9%	14 4.6%	79 25.8%
[ ] provide educational material to consumers	57 18.6%	38 12.4%	28 9.2%	21 6.9%	144 47.1%
[ ] provide educational material to designers and installers	87 28.4%	45 14.7%	21 6.9%	13 4.2%	166 54.2%
[ ] subsidize consumers	80 26.1%	25 8.2%	17 5.6%	11 3.6%	133 43.5%
[ ] subsidize solar industry	20 6.5%	19 6.2%	11 3.6%	10 3.3%	60 19.6%
[ ] other	36 11.8%	5 1.6%	3 1.0%	2 0.6%	46 15.0%