AN ASSESSMENT OF ADVANCED SYSTEMS DESIGNS FOR WATER AND SPACE HEATING

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ABSTRACT

The intent of this paper is to present the results of a study undertaken by the Solar Energy Research Institute in 1987 to identify those ideas which could enhance the acceptability of solar space and domestic hot water heating by the public. A series of two questionnaires were prepared. The first was to solicit industry and researcher perception of the problems faced by the solar industry and to obtain specific technical solutions. Nearly half of the over 100 questionnaires distributed were completed. Once the responses to the first questionnaire were tabulated and analyzed, a second questionnaire was prepared that asked the reviewer to rate ideas which had been identified by the first questionnaire as being technical solutions. Twenty two industry respondents and seven researchers from SERI responded to the second questionnaire. The results show a high correlation as to what both industry and researchers think will succeed. Researchers tended to be more optimistic as to the potential success of various technical solutions.

1. TECHNICAL SUGGESTIONS

The second questionnaire contained two parts. The first asked the reviewer to rate ideas and concepts which were as solutions to increase the acceptability of solar water and space systems. The second part asked the reviewer to assess specific technical solutions. Most of the technical ideas have been identified in earlier studies by Charles Kutscher et al at SERI (1, 2, 3, and 4). The technical solutions are divided into four categories: collectors (C), control systems (CS), storage tank/heat exchangers (T), and systems (S). A brief description of these systems now follows.

DESCRIPTION OF TECHNICAL SOLUTIONS

COLLECTORS

C1 Roof Rafter Collector. Several people suggested using the roof as a collector for a space heating system. Air passageways are constructed underneath the roof between the rafters. Advantages include that the solar heating system is an integral part of the house which eliminates aesthetic problems and reduces the cost of the solar energy system. Typically there is a large amount of roof area to use for energy collection. The removal of energy in this manner might also reduce the cooling load of the house during the summer. Disadvantages include poor collector parameters due to high heat loss and trying to transfer heat from the bottom side of a heated plate, which opposes the natural direction of heat flow.

C2 Collector Convection Suppressor. Heat is lost from a collector by conduction to the support structure (which is usually minimal), radiation from the outer glazing (and from the absorber and through the glazing if polymer glazings are used) and convection from the outer glazing. One way to reduce the heat loss of a collector is to reduce the temperature of the outer glazing which can be done by suppressing the convective heat transfer from the absorber to the glazing. Convection suppressors are designed to improve the performance of flat plate collectors (for water or space heating systems) but tend to increase collector cost.

C4 Collector Glazing Anti-Reflective Coating. Collector performance can be improved by reducing the amount of energy reflected off of the glazing while also reducing the glare off collectors that may offend people.

C6 Extruded Foam Collector. A lightweight, rigid collector is constructed from extruded foam that serves both as the collector body and housing (structural support) and insulation. Channels could be formed in the collector or on the surface during the extrusion process.

C7 Heat Shrink Glazing. A collector is put into a polymer bag which is then heat shrunk to provide both a glazing and a weather barrier. Such a glazing would be well-suited to a collector such as in C6.

C8 Unglazed Roof Collector. This concept for space heating systems would permit the use of low cost collector materials, such as EPDM. This idea has been tried before, but with little acceptance. Such a system would permit rapid installation, eliminate the need for collector supports, and take advantage of the large roof area. The roof under the collectors would be insulated to provide better performance. For metallic absorbers (for example, air blown through galvanized roofing) a durable selective surface paint could be used to reduce radiative heat loss. Convection barriers to minimize heat loss due to wind could also be considered. Significant barriers include appearance and performance. Low-cost, roof collectors might be able to replace regular roofing if designed properly.

C9 Multiple Interior Polyester Glazings. Several layers of high-transmittance polyester would be installed between the outer glazing and the absorber to reduce convective and radiative losses from the absorber.

CONTROL SYSTEMS

CS1 Photovoltaic Control. Typical temperature differential control systems have been prone to problems due to sensor drift and inherent inaccuracies in the electronics to determine the temperature difference of two highly nonlinear devices (almost exclusively thermistors). One solution to this problem, which has recently been introduced to the market, is to control the pump based upon the amount of irradiation for that particular system type. This approach may be well-suited to low flow SDHW systems which attempt to circulate the storage volume about once per day.

CS2 Single Temperature Controller. In this approach, the decision to circulate flow through the collector loop is controlled only by the collector outlet temperature. This would not work with conventional SDHW systems with higher flowrates. But it might work well with low flowrate systems which would circulate the water in the storage tank only once per day through the collectors. Such a controller might be as simple as one snap switch, eliminating much of the electronics.

STORAGE TANKS AND HEAT EXCHANGERS

T1 PCM Wallboard. One of the problems with solar space heating systems is the storage and distribution of the collected energy. Storage requires space and temperature limit sensors while distribution can require complicated controls and interfaces with the conventional heating system. Using wallboard impregnated with phase change material (PCM) solves both of the problem of storage space and distribution. PCM requires less space because it stores energy in the form of latent heat (change of phase, for example, boiling or melting or solid to solid phase changes) rather sensible heat (temperature increase or decrease). Concerns include durability of repeated cycling, heat transfer coefficients to and from the wallboard, and costs. Advantages include a very simple daytime solar air heating system with passive storage and distribution. The large surface area of the walls and ceiling would compensate for low heat transfer coefficients. In addition, heat transfer from the walls to the room would be by radiative (and convective) heat transfer which is efficient and comfortable.

T3 Annual Storage. One problem with solar space heating systems is that they are needed when the potential for solar energy collection is the least. SDHW systems utilize solar energy throughout the year, but space heating systems are generally dormant during the summer. One solution is to collect energy throughout the year and use it when needed. This would require a large storage tank that could essentially store sufficient energy to meet the entire annual heating load. Such an approach would reduce the collector area substantially since energy is collected over a longer period of time and when collector losses are less (because the summertime ambient temperatures are much higher than those in the wintertime for most places with significant heating loads). It would also require a large storage tank which would tend to increase cost and require significant space.

T4 Stratification Enhancement. Much work has gone into researching methods to increase storage tank stratification, which can substantially increase the performance of a water or liquid space heating system (air space heating systems with rockbed storage already have good storage stratification). Some methods include storage tank diffusers or baffles while other techniques involve reducing collector loop flowrates. These methods, which show good results, have not yet had widespread acceptance.

T5 Carpet Pad Storage/Distribution. As described in T1 and T2, storage and distribution of solar energy is a significant problem. This approach solves that problem by using a radiant floor distribution system. The approach would work for new and retrofit applications. A thin mat, similar to a carpet pad, with many small channels would be installed underneath the carpet and double as the carpet pad. Myriads of small channels would permit good flow distribution even though some channels are obstructed by furniture. The auxiliary system could be connected to this system to provide an integrated heating system. Problems include the potential for leaks and poor heat transfer coefficients due to the carpet above it. This approach would require the use of carpets and would preclude the use of (or the heating of) rooms with

wooden or tiled floors. Radiant heat transfer from floors has been used and provides a comfortable environment. This approach uses the building materials to store sensible energy.

SYSTEMS

S1 Low Flow, Direct System. A review of low-flow systems was recently published by Hollands and Lightstone (1987). According to them, reducing the collector loop flowrate to about one-seventh of the conventional value can increase the calculated energy delivered by the solar water heating system by up to 38%. For such a system a simple control strategy, such as a single collector outlet temperature sensor (e.g. a snapswitch), might be effective. Low flow rates also have significantly lower pressure drops in the piping and allow the use of much smaller diameter piping. Small diameter, pre-insulated, flexible tubing would be a possibility and is being produced by one manufacturer.

S4 Freezable Thermosyphon. Thermosyphon systems have many advantages including less components and no control system. Their most significant disadvantage is the lack of inexpensive and reliable protection from freezing. One solution is to develop a thermosyphon system with a collector and associated piping that can freeze without damage (e.g. an EPDM collector with polybutylene piping).

S5 Indirect Thermosyphon. Another approach to designing thermosyphons for cold climates is to design a high performance, indirect thermosyphon. Some of the potential problems include the pressure drop and inefficiencies introduced by a heat exchanger.

S7 Vented, Indirect ICS System. This system is similar to S6 but a load-side heat exchanger is used inside of the ICS storage tank and the pump to maintain pressure in the auxiliary tank and household hot water lines is eliminated. Makeup water to the unpressurized ICS tank can be provided by either manually or by rainwater. The indirect nature of this system is not to provide freeze protection but to allow the use of an inexpensive ICS storage tank.

S12 ICS System with Heat Mirror Glazing. One method to reduce the heat loss from an ICS system, particularly at night, is to use a "heat mirror" on the inside surface of the glazing to reflect radiant energy back to the absorber. The heat mirror has a high reflectance and low transmissivity of short wavelength thermal energy. This results in a lower glazing temperature, since less energy is absorbed by the glazing and hence lower convective and radiative losses from the glazing.

2. INDUSTRY RESPONSE

The industry respondents were asked to rank the technical solutions for their likelihood to reducing cost, increasing performance, improving reliability, having a positive impact on the solar industry and having the highest likelihood for success. The range of the ratings is from +2 (highly optimistic) to -2 (highly pessimistic) with 0 being a neutral rating. A +2 rating would indicate that the idea would accomplish one of the stated objectives above. Taken as a whole the industry respondents were much more positive about the possibility of increasing performance than any other category as can be seen in Table 1.

Given the four categories of technical solutions Table 2 shows the frequency with which industry respondents ranked technical solutions high. Note for example that collectors and systems account for 8 of the top 9 top cost reduction suggestions.

TABLE 1
Highest Rankings per Category

Category	Highest Ranking
Increased Performance	0.95
Cost Reduction	0.67
Probability of Success	0.55
Improved Reliability	0.35
Positive Industry Impact	0.30

The technical ideas were sorted in four categories: collector, control system, storage/heat exchanger, and system ideas. It's interesting to note how frequently these ideas occur in the top ratings of each category. T ble 2 show this comparison. Collector and system ideas account for 8 of the 9 top cost reduction suggestions; collector and storage/heat exchanger ideas account for 7 of the top 10 ideas to increase performance; the majority of top reliability improvements come from system suggestions; the top ideas for positively impacting industry are spread out evenly, except for the lack of control system ideas; and the ideas with the highest probability of success increase from collectors at the lowest end to systems at the highest end. Only two systems ideas and one storage/heat exchanger idea have high overall averages.

TABLE 2
Frequency of Subcomponent Suggestions in Each Category

	Cost Red.	Incr. Perf.	Impr. Rel.	Pos.Imp. on Ind.	Prob. Succ.	Avg.
Collectors	4	3	0	2	1	0
C.S.	1	1	2	0	2	0
Tk/hx	0	4	2	3	3	1
Systems	4	2	5	3	4	2
Total	9	10	9	8	10	3

TECHNICAL SOLUTIONS FOR COST REDUCTION, IMPROVED PERFORMANCE AND RELIABILITY, POSITIVE IMPACT ON SOLAR INDUSTRY AND HIGHEST PROBABILITY OF SUCCESS

The potential range is from -2 to +2 with 0 being an idea that has little impact or any significant improvement in that particular category. It's noticeable that no idea has an average greater than 1. An average rating over 0 implies that there is a tendency towards improvement.

For each technical solution there is a descriptor code consisting of a letter (C, CS, T or S) followed by a number. The letter refers to the technical solution category while the number represents the solution value within that category. A more indepth description of each technical solution is given in the next section.

C: collectors
CS: control systems
T: storage tanks and heat exchangers
S: systems

The cost reduction ideas with ratings of 0 or greater, as shown in Figure 1, are:

C6: Extruded Foam Collector (0.67)
C8: Unglazed Roof Collector (0.62)
C7: Heat-Shrink Polymer Glazing (0.50)
CS2: Single Temperature Controller (0.40)
S1: Low Collector Flow (Direct System) (0.20)
C1: Roof Rafter Collector (0.16)
S4: Freezable Thermosyphon System (0.05)
S7: Indirect ICS Sys w/ Unpress. Tank (0.05)
S5: Indirect Thermosyphon System (0.00)

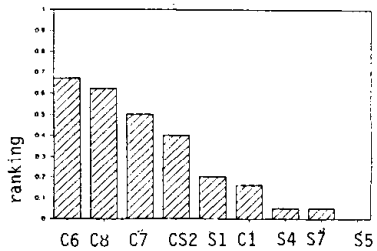

Fig. 1 Cost Reductions

The top suggestions to increase system performance, as shown in Figure 2, are:

C2: Collector Convection Suppressor (0.95)
C4: Collector Anti-Reflective Coating (0.60)
C9: High Transmit. Polyester Glazing (0.57)
T4: Storage Tank Stratification (0.40)
T3: Annual Space Heating Storage (0.38)
S1: Low Collector Flowrate (Direct Sys)(0.30)
S12: ICS Sys with Heat Mirror Glazing (0.29)
CS1: PV Sensor Control System (0.16)
T1: PCM Wallboard Storage/Distribution (0.15)
T5: Carpet Pad Distribution System (0.05)

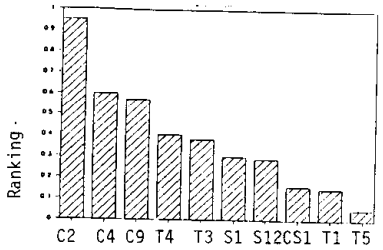

Fig.2 Increase System Performance

The top suggestions to improve reliability, as shown in Figure 3, are:

T1: PCM Wallboard Storage/Distribution (0.35)
CS2: Single Temperature Control System (0.32)
S5: Indirect Thermosyphon System (0.30)
S13: Negative Coeff. Thermosyphon Sys. (0.20)
CS1: PV Sensor Control System (0.16)
S4: Freezable Thermosyphon System (0.10)
S2: Low Collector Flow, Indirect Sys.(0.10)
S1: Low Collector Flow, Direct System (0.05)
T3: Annual Space Heating Storage (0.00)

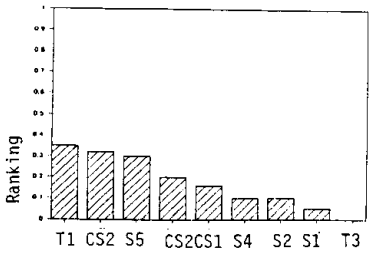

Fig.3 Improve Reliability

The top suggestions that have a positive impact on the solar heating industry, as shown in Figure 4, are:

T1: PCM Wallboard Storage/Distribution (0.30)
S5: Indirect Thermosyphon System (0.30)
C6: Extruded Foam Collector (0.29)
C5c: Collector Thermochromic Glazing (0.19)
T4: Storage Tank Stratification (0.15)
S1: Low Collector Flow, Direct System (0.10)
S4: Freezable Thermosyphon System (0.05)
T5: Carpet Pad Distribution System (0.00)

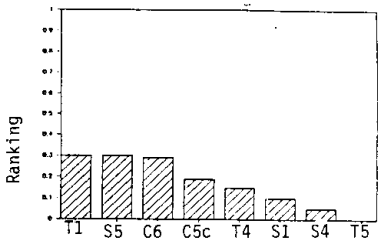

Fig.4 Positive Impact on Industry

The top suggestions with the highest probability of success as shown in Figure 5, are:

S1: Low Collector Flow, Direct System (0.55)
T4: Storage Tank Stratification (0.25)
T1: PCM Wallboard Storage/Distribution (0.20)
CS1: PV Sensor Control System (0.20)
S2: Low Collector Flow, Indirect System(0.10)
T9: Tank-in-tank Storage Drainback Sys.(0.10)
CS2: Single Temperature Control System (0.10)
S5: Indirect Thermosyphon System (0.05)
C2: Collector Convection Suppressor (0.05)
S12: ICS Sys. with Heat Mirror Glazing (0.00)

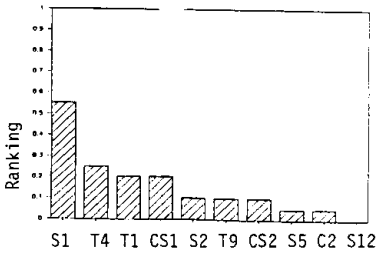

Fig.5 Highest Probability of Success

3. RESEARCHER RESPONSE

The researchers were considerably more optimistic in their assessment of the technical solutions than industry as shown in Tables 3 and 4. Researchers ranked ideas at 1.00 or higher in four of the five categories while industry had none.

TABLE 3
Highest Rankings per Category

Category	Highest Ranking
Improved Reliability	1.14
Cost Reduction	1.00
Increased Performance	1.00
Probability of Success	1.00
Positive Industry Impact	0.86

Table 4 shows the number of ideas listed by subsystem type that had a ranking of 0 or higher in each category. While researchers had rankings of 0 or higher 110 times industry respondents had this 46 times.

TABLE 4
Frequency of Subcomponent Suggestions

	Cost Red	Incr. Perf	Impr. Rel.	Pos.Imp on Ind.	Prob Succ.	Avg
Collec.	5	3	4	6	7	2
C.S.	3	1	2	2	2	2
Tk/hx	2	6	5	5	6	7
Sys.	9	8	11	13	10	8
Total	19	18	22	26	25	19

The top seven ideas as ranked by researchers to reduce costs were:

C8: Unglazed Roof Collector (1.0)
C6: Extruded Foam Collector (1.0)
CS2: Single Temp. Control Sys. (0.86)
S6: Vented Direct ICS Sys. (0.86)
T8: Water Bed Bladder Strge. (0.86)
C1: Roof Rafter Collector (0.83)
C7: Heat Shrink Coll. Glazing (0.71)

Researchers rated 18 ideas at 0 or higher for increased performance in contrast to 10 by industry. The top 5 suggestions included:

S1: Low Coll. Flow, Direct Sys. (1.00)
S10: ICS Nighttime Insulation (0.86)
C4: Coll. Glzg. Anti-Refl. Coating (0.86)
C2: Coll. Convection Suppressor (0.86)
T4: Storage Tk. Stratif. Enhance. (0.71)

Researchers rated 22 ideas at 0 or higher for improving reliability compared to 9 by industry. The top 5 were:

S9: PV Heated Water (1.14)
CS2: Single Temp. Control Sys. (0.86)
S4: Freezable Thermosyphon Sys. (0.86)
CS1: PV Sensor Control System (0.86)
S5: Indirect Thermosyphon Sys. (0.57)

Researchers rate 22 ideas at 0 or higher for having a positive impact on the solar industry in contrast to 9 by the industry itself. The top 6 were:

CS1: PV Sensor Control System (0.86)
S5: Indirect Thermosyphon Sys. (0.86)
C4c: Coll. Thermochromic Glazing (0.83)
S4: Freezable Thermosyphon Sys. (0.83)
S6: Vented, Direct ICS System (0.67)
S7: Vented, Indirect ICS Sys. (0.67)

There were 25 ideas ranked higher than 0 by researchers for having a high probability of success in contrast with 10 by industry. The top five ideas were:

S1: Low Coll. Flow, Direct Sys. (1.00)
CS1: PV Sensor Control Sys. (1.00)
C2: Coll. Convection Suppressor (0.67)
S7: Vented, Indirect ICS Sys. (0.67)
S2: Low Flow, Indirect Sys. (0.60)

The average of the five averages for cost reduction, improving reliability, improving performance, positive impact on the industry, and probability of success had 19 ideas above 0 by researchers compared with only 3 by industry (S1: Low Coll. Flow, T1: PCM Wallboard, and S5: Indirect Thermosyphon Sys.). The overall top 9 ideas by researchers included:

CS1: PV Sensor Control Sys. (0.69)
S1: Low Coll. Flow, Direct Sys. (0.63)
S4: Freezable Thermosyphon Sys. (0.46)
CS2: Single Temp. Control Sys. (0.46)
S5: Indirect Thermosyhon Sys (0.43)
S2: Low Coll. Flow, Indirect Sys. (0.40)
S7: Vented, Indirect ICS Sys. (0.38)
S6: Vented, Direct ICS Sys. (0.38)
T1: PCM Wallboard Storage and Dist. (0.31)

System type solutions predominate the top half of the overall rankings by the researchers. Of the 19 overall technical solutions rated 0.0 or higher, eight are system ideas, seven are storage/heat exchanger ideas, two are control system ideas and two are collector ideas. Two of the three control systems ideas ranked in the top four places.

4. Conclusions

Apart from the higher rankings by researchers there is a good agreement between what both researchers and industry think will succeed. The main difference is that researchers are more optimistic about the success of the technical solutions than the solar industry participants. However, in nearly all the cases of ideas ranked 0 or higher by industry, were also ranked 0 or higher by researchers.

There were some differences of opinion between the two groups. Industry rated the carpet pad distribution system (T5) highly for increasing performance and having positive industry impact and annual space heating storage (T3) for improving reliability. Neither of these ideas were supported by researchers. Researchers felt that ICS nighttime insulation (S10) would increase systems performance, that PV water heating (S9) would improve reliability and that PV sensor control systems (CS1) would have a positive impact on the solar industry. Industry respondents did not share the same optimism.

Two of the top five selections by the researchers correspond to two of the top three selected by industry namely, low collector flow direct systems (S1), and indirect thermosyphon systems (S5). Both are from the systems category of solutions.

Historically, solar heating systems have progressed from emphasis on components to an emphasis on systems. The solar industry learned that highly efficient and reliable components did not necessarily lead to a highly efficient and reliable system if they were not integrated properly. The natural progression is now to consider the integration of the solar heating system into the home.

Although by no means exhaustive a number of technical ideas were identified by both industry and researchers as showing merit in some aspect of performance, cost or acceptability. Many of these promising ideas and concepts should be carefully considered and then developed and tested. A well designed long term program of study and testing should be developed that weaves together the remaining elements of the solar industry and those engaged in solar research.

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