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ASSESSMENT OF NEEDS FOR NEW CONTROLLERS

Final Report

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MASTER

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FINAL REPORT

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JULY 1980

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ABSTRACT

A survey was conducted to evaluate currently available controllers for solar systems and to determine the need for new control devices and for improvements to present ones. A detailed discussion of the survey results is included and individual responses to the survey are listed. Part I concludes with recommendations for possible future R & D efforts.

1. INTRODUCTION AND SUMMARY OF RESULTS

OBJECTIVE

The object of the project was to:

- 1) ascertain the capabilities of currently available solar controllers,
- 2) identify additional requirements for new controllers, and
- 3) recommend appropriate development efforts for new controllers.

METHODOLOGY

The information was gathered from the 128 responses to a mail survey and from direct review with eighty solar industry representatives. Survey participants included:

- 1) current solar system manufacturers,
- 2) current solar equipment distributors,
- 3) current solar equipment dealers and installers,
- 4) controller manufacturers,
- 5) building architects and engineers, and
- 6) solar engineering consultants and designers.

Follow-up in-depth discussions were conducted with respondents who had technical recommendations and comments. Technical interviews were also conducted with the engineering and program managers of more than fifty leading solar system manufacturers.

SUMMARY

PRESENT DOMESTIC H₂O CONTROLS

The overwhelming majority of the presently available controllers are differential thermostats designed for regulating domestic water heating or for the collection cycle of the solar space heating system.

These differential thermostats typically use thermistor sensors, low voltage, have a quad-amp logic circuit and a line voltage switching output. These choices of outputs are evenly divided among the various manufacturers between relay and solid state.

Because of the quad-amp circuit, each manufacturer can usually economically modify his standard differential thermostat to make three other comparative decisions, i.e., freeze protection, boil protection, etc. The bulk of the additional cost is usually represented by the additional sensor and switching output expense.

More than thirty-five firms make differential thermostats for the

domestic water heating function. It was the consensus of the responders that presently available control equipment is generally adequate for now and the near future. The major technical shortcomings were with reliability and field installation. Some improvements are needed to simplify installation, increase reliability and handle extreme temperature (i.e., freeze and boil) situations. Many respondents pointed to the need for improved installation instructions for all controllers. Greater detail and increased clarity of installation and operating information will go far toward improving customer satisfaction with control devices. Reliability should be improved as manufacturers gain more experience and feedback regarding use of their products in the field.

Virtually none of the H₂O users were conscious of the technical aspects (e.g., thermal time constant) of control of water systems. As such, specifications of probe accuracy, differential offset, hysteresis range, etc., are not included in most equipment design specifications. Rather, "if the sun is shining and the machine goes 'click'", the performance is adequate. However, as the level of expertise increases among control users, these aspects of the control picture will become more important.

The trend among manufacturers of tanks and similar packaged systems is to eliminate the controller sub-assembly and to design the electronic control module into a prewired unit with the pump. None of these manufacturers were committing to additional sophistication such as advanced algorithms, microprocessors, user override, etc. Cost considerations appeared to be important in their decisions. Also, the feeling was expressed that control functions should be kept simple for the sake of the user, and that the increased efficiency to be gained by adding more "bells and whistles" was not sufficient to justify their cost.

The fact that periods of heaviest usage of domestic hot water (usually early morning and late evening) do not coincide with the time of availability of solar energy is a problem inherent in the use of heat for solar domestic hot water systems, which reduces the possible efficiency of the operation. A solution is to control the time of usage to coincide with periods of greatest insolation; for example, to turn on dishwashers, automatic washing machines, etc., when solar heated water is available. If automatic turn-on for these devices is found to be desirable, this control function is accomplished in a rather simple manner using methods currently available.

SPACE HEATING CONTROLS

A large number of solar engineers and system designers thought of space heating control as a combination of a differential thermostat for collection and a two-stage thermostat for distribution. Because of the simplicity of hook-up, most installers are satisfied with this control strategy. This will send collected heat only to storage,

rather than using it to heat the living space directly, often resulting in the need to use auxiliary heat because the storage is not hot enough, even though the sun may be shining brightly -- a somewhat inefficient operation.

Only firms which had either adequate data and technical staff or HVAC experience actually observed the shortcoming of this type of control strategy. It has become clear that systems designers must be educated, installation must be simplified, equipment reliability increased and installers trained before the most efficient, comfort-regulating control strategies achieve widespread acceptance.

MULTI-MODE CONTROLLERS

Among dealers and installers there was general dissatisfaction with available "multi-mode" solar space heating controls. The problem had three dimensions: 1) electronic designs not specifically addressed to HVAC interfaces; 2) lack of standardized system designs so that standardized strategies could be hard-wired; and 3) lack of analytic and electronic skills within the solar installation field.

Improved communication between electronic designers and the HVAC industry will be important in relieving the first problem area. While system design may become standardized to some extent, it seems safe to assume that numerous strategies for operation will continue to be employed, necessitating a number of control logic sequences. Improvements in installation instructions and diagrams will occur as manufacturers prepare for an increasing market. At the same time, training sessions for installers and dealers would familiarize them with control functions and installation.

As solar applications become more complicated, incorporating cooling, heat pumps, domestic hot water heating, etc., into one system, the demand for more sophisticated controllers is increasing. Now several differential thermostat control manufacturers are committing to the manufacture of "multi-mode" controllers. But lack of standardized logic is an impediment, and most controllers must be modified to fit the particular system design. This is fairly easy at the O.E.M. level, but very difficult at the dealer/installer level, because of lack of programming skills.

VARIABLE FLOW VS. "BANG-BANG"

Opinion was divided on the practicality and the necessity of variable speed flow versus "bang-bang" control. Almost without exception, the variable speed advocates felt that their technique would yield slightly better collection efficiency. Because this method uses a small differential turn-on offset (usually about 2°F), it will cause collection of heat for a longer portion of a normal day, and will also allow some

heat to be collected during partly cloudy periods. The variable speed feature is said to greatly reduce cycling of the pump or blower, which is the drawback of using a "bang-bang" controller with small turn-on offset. In fact, the latter method would achieve efficiencies similar to the former, but the user would have to tolerate the often annoying cycling. Only one major user of the variable flow technique observed this shortcoming of the technical argument, but he allowed that it provided "sizzle" to his sales promotion.

A variable flow controller (often incorrectly referred to as a proportional controller) operates by controlling the pump speed and therefore, modulates the collector-to-storage flow rate. It does this by interrupting the electrical power to the pump by using triac output able to chop the input power's individual half-wave or to modulate the number of full wave forms being delivered to the pump. The duty cycle of the interruption is a ramp function of the ratio of collector to storage temperature differential, typically over the 30° to $110^{\circ} \pm 10^{\circ}\text{F}$ differential. Fluid flow is started through the panel as soon as energy is available. The low flow rate allows for a low turn-on temperature and minimizes the thermal shock and eliminates the requirement for hysteresis. Claims for increased collection when compared to high offset bang-bang systems by as much as 6% to 8% in cloudy and overcast conditions are made by the manufacturers. Optimum control theory analyses show that the higher flow rate bang-bang if used with a low turn-on and hysteresis is more efficient. But the user must be able to tolerate cycling. Hence the real advantage realized by the variable output controller does come from the elimination of the typically large turn-on offset so that a longer collection duty cycle is obtained in intermittent cloudy weather. This advantage is achieved with low speed pump operation and without the customer perceived pump hunting that would occur in a bang-bang system with this low turn-on temperature and small dead band. Since the pump is actually being turned on and off by the triac switch many times each second, only pumps with series wound motors (permanent capacitor, shaded pole, etc.) which are recommended for this type of use should be utilized. The effects of either the low voltage chopped wave or the rapid on-off of the full wave modulated outputs should be reviewed with the pump supplier. Tests also support the analysis that this type of pump operation results in marginal (if any) electric energy reduction.

Other problems are inherent in the variable speed approach because these controllers have solid state rather than mechanical output. They are prone to failure of the output stage, exhibiting progressive failure modes with inductive loads, and field installation is difficult, due to the lack of experience among installers in working with solid state devices.

SWIMMING POOL & SPA CONTROLLERS

The industry is generally dissatisfied with the reliability of existing pool controllers. No recommendations received widespread endorsement. However, a few special features, such as night-time cooling, pool sweep inhibit and low voltage (12 V) three-way valves were recognized as desirable.

TESTING & CERTIFICATION

Most responders agreed that Underwriters Laboratory approval for safety is necessary, but felt that certification of performance would be expensive and unnecessary. The suggestion was made that government funding might be made available to pay for UL testing, in order to take the cost burden off small companies. Rather than asking for legislation to assure performance certification, it was felt that the industry would set the standards itself, and that warranties or guarantees from manufacturers would handle problems of poor performance. The problem here is that each component manufacturer warrants his product, but there is not necessarily a performance guarantee for a complete system made up of diverse components. More cooperation among component manufacturers and suppliers is needed here; it should not be necessary for government regulation to take over this area. However, as more solar systems are put into operation, local codes will probably become more specific regarding some requirements.

COST IMPROVEMENT

As might be expected, all users would like reduced cost. It is hoped that cost reductions to be gained through increased sales volume and larger production orders will not be completely offset by the effects of inflation. Standardization of control strategies could be very helpful in effecting reduced costs. Some cost improvement for complicated control strategies may be available through the use of Programmable Read Only Memory (PROM) to implement the control logic. Since these devices can be removed and replaced readily, field installation would be simplified, and the PROM could be replaced quickly if the need should arise for a change in the control logic. This approach also shows promise as a way to fulfill the control requirements for rather complex systems. On the other hand, the use of microprocessors appears not to be cost effective at this time, except for very complicated systems, or those applications where other parameters (e.g., lighting control, energy management, etc.) are to be included in the control strategy.

INSTALLATION AND TEST INSTRUCTIONS

Many respondents pointed to the need for improvements in installation instructions, to make them easily understood and utilized by installers and dealers. Specific requests were made for improved field wiring diagrams, and for troubleshooting and field test instructions to indicate whether or not the controller is operating properly. Instructions should specify the proper location of the temperature sensors for both collector and storage to achieve the greatest efficiency. Also needed is improved education in the use of controls for system designers and for installers.

The Solar Energy Research Institute (SERI) has a handbook under preparation that addresses this problem for the various domestic hot water system configurations. To date, no similar program is under way for space heating systems. Installers were particularly bothered by the many system configurations, thermostat circuits, auxiliary heater and heat pump circuits, etc., that they encounter in the space heating market.

MICROPROCESSORS

Most respondents felt that the solutions to the present problems would result in a microprocessor-based unit in two to five years. Few recognized that the major technical problem is one of algorithm development (in order to justify a "number cruncher"), and that the major cost and reliability barrier is in the power switching device. Initial microprocessors will have additional display and timing functions, but will not be performing classical optimum control computations. These computative and self-diagnostic capabilities would justify a microprocessor-based machine. In the interim, cost effective integrated circuit chips are becoming available for control applications. A device of this type operates as a differential thermostat and may have the capability for adjustable temperature differentials.

OTHER COMMENTS

The majority of respondents indicated that the thermistor temperature probes used in their control equipment are satisfactory. They saw the need for high impedance sensors with high signal to noise ratio, and realized that the circuit designs were emerging that could accommodate the non-linear response. Many expressed a desire for operator override capability as an aid in check-out procedures, and also as a precaution in case of problems with the automatic system.

GOVERNMENT PARTICIPATION

Almost all respondents were vehemently opposed to government subsidy for development of new controllers. It was felt that demands of the marketplace would lead to development as it is needed, while keeping costs down. Private enterprise would use its own capital more effectively to answer the needs of the controls market, as has historically been the case for other industries. Government subsidies have not always achieved the goals set for them, and might result in government control of the industry, which was considered undesirable. Funding for applied research and for UL or independent laboratory testing and approval were the only areas mentioned where government help would be acceptable. It was felt that the government should collect and pass along the information that manufacturers and designers need for decisions regarding component development. Specifically, computer modeling of different systems could produce important information leading to further improvements.

FUTURE DIRECTION

Several areas of concern are addressed by equipment now becoming commercially available. In the case of water systems, there is a continuing discourse on which type of freeze protection is preferable: anti-freeze, recirculation or drain-down; the particular system would probably dictate the choice. Freeze protection which would operate in spite of a power failure was of prime importance to some respondents. Others requested that attention be given to lightning protection for control devices. Ability to adjust turn-on and turn-off differential in the field would help to provide greater efficiency and flexibility. Anticipatory response to ambient temperature changes would be helpful in improving comfort level and therefore user satisfaction with solar systems.

More sophistication is desired in control of air systems to reduce the parasitic energy consumption of the blowers. Use of variable speed blowers or feedback loops was suggested. Home thermostats which can be operated synergistically by the user according to his needs are viewed as an asset to the widespread use of solar. Passive systems and combined passive-active systems are becoming more widely used; these will require specialized controllers. Further development is needed in devising more sophisticated control strategies and equipment to interface with heat pump applications and to handle utilization of off-peak power. Controllers that would measure as well as control temperature (e.g., using digital read-out) were mentioned as desirable.

Expanded applications of solar energy will generate the need for new control methods and systems in many areas. In the future, control

applications will become more important for industrial process heat, for solar operated distillation processes, and in greenhouse, spa, and swimming pool applications. Energy management, peak power demand regulation or load shedding, and fuel consumption measurements will require more sophisticated control strategies when combined with solar systems.

RECOMMENDATIONS

As a result of this survey, the following recommendations are made:

- 1) A handbook on solar space heating and cooling systems for system designers and installers should be prepared. It should include information about both air and liquid transport systems, along with instructions for interfacing with various auxiliaries, including duct heater, gas fired furnace, hydronic heating, heat pump, etc. The various heat pump configurations should be described, with instructions for integrating them into a solar system. Problems of interface with the various solar types of cooling as well as with the more common air conditioning methods should be addressed.
- 2) There is a need for development of algorithms for more sophisticated controls, including microprocessors. With the increasing solar market, more elaborate control strategies are becoming necessary. For instance, when a solar system is used in conjunction with energy saving and management methods, the required control strategies become rather complex. Perhaps some funding from the government would help to promote the development of the needed algorithms.
- 3) There is a requirement to develop solar/heat pump algorithms with the capability to enhance system COP and provide present day comfort levels, as well as to protect the compressor and utilize off-peak rate advantages. Ideally, the hardware should provide multi-speed outputs for the heat pump modes.
- 4) Thermostats should be developed specifically for use in solar applications. Ideally, these would be designed to function with conventional or heat pump back-up, for both heating and cooling, and could be operated synergistically by the user to maintain comfort levels while conserving fuel.

II. DISCUSSION OF RESPONSE

A separate questionnaire was developed for each of three types of respondents: 1) manufacturers, 2) installers and distributors, and 3) architects and engineers. A total of 750 surveys were mailed; 128 individual responses were received. About 100 questionnaires were returned because the addressee was no longer in business. Responses were fairly evenly distributed among the three groups, although architects and engineers contributed the greatest number of replies.

The following is a discussion of responses to each question. Appendix A provides details of the questionnaires. The first question asked the respondents to identify to which of the three groups he belonged. Comments and statistics begin with Question 2.

Question 2: Type of system you deal with primarily

- Space Heat
- Space Cooling
- DHW Heating
- Agricultural
- Pools
- Industrial Process Heat
- Other

Most responded that they dealt primarily with space heating and domestic hot water systems. The next most frequently mentioned system areas were swimming pools and space cooling.

Question 3: Is the type of system you deal with primarily for:

- Single family residential
- Multi-family residential

Overall, 58% dealt with single family residential systems, and 42% dealt with multi-family residential or commercial systems. Among engineers the percentages were 51% dealing with single family systems and 49% with multi-family or commercial systems. There were no specific comments for this and the following two questions.

Question 4: What type of temperature sensors are used with your controllers:

- Thermistor
- Thermocouple
- Diode
- Transistor
- Other

Thermistors were used by most (69%) of those responding; none used diodes. Thermocouples were used by 15%, transistors by 4%, and other types of temperature sensors were used by the remaining 12%.

Question 5: What type of system will show the greatest growth in the next 10 years?

Overall, 40% feel that domestic hot water heating will show the most growth. Space heating was specified by 29% of those responding and industrial process heat was cited by 11%, while 9% said pools. Space cooling (6%), agricultural (3.5%) and others (1.5%) accounted for the rest. The only group which differed significantly from these was architects, among whom 43% feel that space heating will show the most growth, 38% feel DHW heating will grow the most, and 10% said agricultural systems will experience the greatest growth.

Question 6: Existing control strategies are:

Too simplistic
Appropriate
Too sophisticated

Overall, most (64%) felt existing strategies are appropriate "to present requirements" provided that "the right controller and the right manufacturer is chosen for the application." However, many mentioned that the controls should be better matched to specific system interfaces and that "no means is usually provided to test controllers in place to see if they work properly."

Among manufacturers, installer, distributors, architects and others, as a whole, 61% responded "Appropriate" and 22% said "Too simplistic." The feeling seems to be that "simple strategies fail to optimize on heat collection and use" and result in "lower system efficiencies."

Overall, 24% felt strategies are too simplistic, citing the need for codes and regulations ("standards badly needed") and the need for efficiency optimization - "eventually what we need are total energy use control devices which will optimize energy utilization and demand."

Of those 12% who responded "Too sophisticated", most commented that "costs are too high and application complicated" and that "lower cost is needed and will result with increasing market." It was stated that "it is difficult to find durable, cost-effective components," and that "controls should be kept to a bare minimum to eliminate service and maintenance problems." The statement was made that "systems must be simplified if they are to be successful on the residential scale."

Question 7: In their ability to maximize system effectiveness, present controllers:

Leave much to be desired
Are o.k.
Couldn't be much better

Overall, only 6% responded "couldn't be much better," stating that "for flat plate collectors, additional complexity is not worth the small increase in efficiency." Most (59%) felt that controllers "are o.k." and 36% felt they "leave much to be desired."

Among engineers, 51% see controllers as "o.k.", while 42% feel they "leave much to be desired." Of manufacturers, similar responses were obtained: 56% said "o.k." and 35% said they "leave much to be desired." Among architects, however, most (58%) responded that controllers "leave much to be desired"; only 33% see controllers as being "o.k."

Many seemed to feel that strategies are o.k. "for space and DHW for residences" and for "small, basic systems," but that they "need improvement in reliability," as well as installation practices, including sensor placement. Proportional controls and adjustable differentials were considered important by many.

Among those who see controllers as leaving much to be desired, it was felt that "control strategy (is)* too simplistic" and more long-term testing (is) required to rate effectiveness." It was also stated that "functionally, most differential thermostats are adequate; however, they require some improvement as concerns cost-effectiveness." Lack of "total system controls for heating - cooling," lack of test procedures, and relay chatter were cited as shortcomings of current controllers. One respondent objected to solid state logic. Finally, it was commented that "if you mean by 'system' a solar heating system, we're o.k. If you mean the total comfort system coordination and effectiveness, we have a ways to go."

Question 8a: Should controllers be inspected and certified: For safety?

Overall, 74% responded "yes," but among architects, only 55% said "yes." Of those who responded "no," most said "this adds cost" and is "probably not necessary," as "survival of the fittest will apply." Some felt certification unnecessary due to the low voltages employed by most controls. The statements were also made that inspection and certification should not be "by federal agencies; industry control is more in keeping with free enterprise" and that such federal inspection would "put the S.E. (solar energy) industry into a governmental straightjacket of regulations!"

Among those who said "yes," most felt that "UL approval would be sufficient" and that "exorbitant inspection fees must be avoided." One comment was, "Absolutely! Fire and life safety codes should be STRICT." Some felt that "independent laboratory listing" would be sufficient and the statement was also made that "testing by a nationally recognized independent testing laboratory offering follow-up service is a must. UL LISTING SHOULD NOT BE REQUIRED." On the other hand, it was also commented that "UL listing (is) a must - local certification ambiguous," and that "UL approval is generally desirable."

*Words in brackets were added by the authors.

Question 8b: Should controllers be inspected and certified: For performance?

Overall, 73% said "yes," but among manufacturers, only 58% responded "yes." Of those who said "no," a frequent comment was that "the market will eliminate the inferior products" and that this would be "more cost-effective than a government sponsored testing program." Others said that "this is an unnecessary cost," the feeling being that "a manufacturer's performance warranty is more effective consumer protection. Testing cannot deal with reliability and service life as effectively as a warranty can." Some felt that performance inspection and certification would be meaningless because "the concept of what a controller should do is too varied."

Among those repoding "yes," most felt certification is desirable "to prevent false claims of performance" and to substantiate manufacturers' "claims made in sales and engineering literature." Many felt that manufacturers should be required to publish test results, including MTBF (mean time between failure) and sensor performance. Others saw a need for "some type of warranty or guarantee of performance" but only when a thorough and fair evaluation scheme is developed" for the "elimination of poor quality products." "Minimum and maximum performance guarantees should not be legislated." Finally, the comment was made that "we experienced 100% failure in one run of 50 units!"

Regardless of a "yes" or "no" answer, most viewed inspection and certification for performance as "an industry function," outside any government program.

Question 9: Installation of present controllers is:

- Easy
- Manageable
- Too difficult or expensive

Overall, 49% of those responding felt installation is "manageable" and 35% feel it is "easy."

Among the 16% who responded "too difficult or expensive," typical comments received were, "field personnel are not qualified to install the average IC type control device" and that "even the simple control systems are too costly."

Of those who responded "manageable," many stated that "better field wiring diagrams (are) needed," and it was also commented that "one manufacturer supplied incorrect wiring schematic." In general, it was felt that what is needed is "more published data on installation practice." One comment was, "the only complaint is that too much labor is involved," but installation is "manageable if (it) is planned properly." Several suggested "plug-in configurations" to simplify wiring. Finally, it was stated by one installer that "as manufacturers receive input from installers like myself, changes will take place - some already have!"

Question 10: Maintenance service is:

Readily available
Marginal
Very scarce or expensive

Overall, most (44%) responded "marginal." 32% feel that maintenance is "very scarce or expensive," while 24% answered "readily available." Among manufacturers, 36% feel that maintenance is "readily available," 24% finding it "very scarce or expensive." Among engineers, however, 44% find maintenance service to be "very scarce or expensive," only 16% reporting it to be "readily available."

The difference between manufacturers' and engineers' perceptions of service is probably because, at the present time, "replacement through the factory is the only maintenance available," as the "average serviceman is not knowledgeable enough," but that this is mainly "due to 'newness', not complexity."

Maintenance service, it was stated, "will be the greatest drawback. Trained technicians are URGENTLY NEEDED." Comments reflected the need for trained servicemen, some suggestions being "training programs must be added ...to increase servicemen's ability in these types on controls;" perhaps "manufacturers could have one-day schools across the country to help installers understand their controls." Also, it was stated that "troubleshooting instructions should be included," as "most manuals and troubleshooting guides are inadequate." Other complaints included long turn-around time at the factory and lack of support from manufacturers. However, several felt that this area is "not critical," since "little (is) required."

Question 11: What are the major shortcomings of existing controllers?

Installation difficulties were cited as one major shortcoming: "Difficult to install and expensive maintenance due mainly to tradesmen's unfamiliarity" which reflects the "need (for) better field installation and maintenance manuals."

Reliability was frequently stated to be a problem. "Reliability leaves much to be desired," and "all components should be fully tested and approved for 'Fail-Safe' operation." In conjunction with the question of failure, maintenance costs were also cited: "Any sort of 'failure' requires a service call which costs excessively in relation to first cost" and "continuous service to repair controller is expensive."

Another recognized shortcoming was "prediction of performance and cost." One comment was, "Cost should be under \$50.00 from any manufacturer."

Another problem cited was "limited control logic. Controllers need to measure as well as control. The addition of a temperature meter and adjustable set points would be very useful." One respondent mentioned "limited output functions," but "adjustable thresholds on some controllers

might be an improvement." While one comment was that controllers are "more complicated than need be," another stated that controllers "should be able to handle more complex systems (preheat and final heat, heating and cooling modes, etc.) with one control module;...should be able to expand capabilities at minimal cost increase, as well as reduce cost of simple differential thermostats by utilizing state of the art components and fabrication techniques." Other problems included sensor mounting and low output power. About one fifth felt there are "no major shortcomings."

Question 12: Should controllers have a user override capability?

Overall, 81% responded "yes," 12% said "no," and 7% had "no opinion." The only significant deviation in opinion on this question occurred among architects, of whom 100% answered "yes."

Question 13: What type of switching do you prefer?

Solid state
Mechanical relays

Overall, 76% preferred solid state, but among architects, 100% preferred solid state. Some points made about solid state switching were "quality components are more dependable" and although "solid state relays (are) difficult to trouble-shoot, (they) hold better promise for a lower failure rate." It was stated that "solid state offers the advantage of having no 'contacts' to pit or misalign and can also be used for proportional output" and also has the "potential for much longer lifetime."

Conversely, many felt that "solid state is still too limited and expensive" and that solid state would be preferred "if it were as reliable as mechanical relays and could be repaired as easily." Two specific problems with solid state were stated to be "switching large motors 1/3 hp and over" and "locked-rotor faults."

Mechanical relays were preferred for a variety of reasons, because they are "easier to trouble-shoot and maintain," "easy to replace and procure," and that "solid state is costly by comparison and does not justify (the) extra expense. Also, it was stated that "mechanical relays are more easily serviced by inexperienced help," "the local HVAC or plumber contractor must understand how to repair it," and the "plumbing and heating trade is most familiar with mechanical relays." Mechanical switching was felt to be "desirable for freeze-protection functions" and preferable for pumps and power.

In addition, there were those who felt that switching "depends on application" and "upon output requirements." Several favored combinations of the two: "solid state (is better) for logic, mechanical relays for power."

Question 14: Specify the features, in order of importance, that you look for in a controller:

- Cost
- Ability to perform specified task
- Appearance
- Lighted display
- Size
- Power requirements
- Ease of installation
- Maintenance
- Other

The most important feature, cited by 85%, was the ability to perform the specified task. Cost emerged as next in importance, 58% rating it second. Maintenance seemed to be the next feature sought, 34% ranking it third. Thirty-six percent rated ease of installation as the fourth important feature, power requirements were considered (by 28%) as fifth in importance, and size emerged in sixth place (so ranked by 36%). Appearance and lighted display were the least important features sought.

Question 15: Are presently manufactured controllers adequate for most present day applications?

Overall, 66% responded "yes," and 34% said "no." Manufacturers were more split in their feelings; 56% answered "yes" and 44% said "no." Most of those who responded "yes" and made comments feel that controllers are "too costly" and that they "can be improved." The need was also cited for "better product development efforts," "more sophisticated controllers in the near future," and an "integral fuse to control possible damage to the unit." It was stated, too, that "the marginal cost of more sophisticated devices is too great to warrant their use in small systems."

Conversely, it was commented that presently manufactured controllers are "too complex and not basically satisfactory" and that "too much custom engineering (is) required." Comments were also made that "poor control drastically cuts system efficiency" and that "there are great improvements possible in reliability." Other comments were that "differential thermostats should have field adjustable set points and differentials" and that present controllers "do not interface well with needs."

Question 16: Do presently manufactured controllers perform as claimed?

Seventy-one percent responded "yes," stating that "units are performing as planned" "within reason." Of those commenting who answered "yes," many felt controllers are "too costly," "can be improved," and "need better product development efforts." It was stated too that "printed circuit types are impossible to service" because it is "hard to determine problems with them." Comments were also made that controllers perform as claimed ("when they aren't needing repairs"), "although sometimes not as long as you would wish them to."

On the other hand, some of the 29% who responded "no" felt that "many

claims (especially for proportional controllers) seem somewhat optimistic," and system performance has not been documented sufficiently to verify claims." One comment was, "evidently some large percentage of new controllers don't work properly," and another, "cycling is a problem with some controllers (and) not enough attention is paid to informing users/installers of proper locations for (most satisfactory) sensor response."

Question 17: Please list any future areas where you feel there will be a need for new types of controllers.

As one comment stated, "all areas" will experience a need for new types of controllers. Cited most frequently was a need for "total energy management systems in future energy conserving dwellings." This could be accomplished with "domestic energy management systems, including load shedding and peak demand regulation, (and) controls to adjust and fine-tune the HVAC equipment of all types and sizes according to varying heating and cooling loads," in conjunction with "sensible heat storage" and "complete comfort (humidity, etc.)" control. With respect to passive systems, the need is controls for movable "insulation, baffles, shades, etc."

Many comments stated a need for "easily programmable controllers" and "add-on logic for system application," because "microprocessors have not been exploited to their capabilities for any application." Also cited was the "need to provide more data about systems 'health', i.e., how well it is converting solar energy," suggesting "remote readouts of system temperatures" and "house temperature solid state readouts" would provide more data about a system. In addition, it was commented that there will be a need for "improved differential thermostats."

Another area cited was controllers "for harsh environments such as greenhouses and livestock buildings" and "agricultural systems." "Solar industrial applications" and "large system applications with multi-mode operation" were also listed, as were "solar assisted heat pumps" and "heat pump systems/heating and cooling," and "solar stills." One comment stated a need for "'smart controllers' with anticipatory response to house load (rate of ambient temperature usage); controllers that indicate and describe system malfunctions; controllers that turn pump full on to clear air out of the system, then cut back to proportional operation." Other areas mentioned were "combined systems" such as greenhouse/space heating and pool/space heating, freeze protection, cooling, monitors and "tracking."

Question 18: Should the development of new controllers be subsidized by the government?

Seventy-four percent responded "no," 19% "yes," and 7% had "no opinion." Of the comments received, only one was in favor of government subsidy, and that comment was "yes, if no strings are attached to it (such as 'claims' or 'ownership')."

The feeling among those who commented "no" was largely that "private capital should be used as proof of market confidence and cost efficiency of manufacturers." Also, it was stated that "government intervention will

result in government control of the industry. Controls technology will best grow as a result of the natural growth of the industry." Citing "what has happened to this industry so far," it was commented that "thus far, government subsidies connected with solar, such as HUD initiative, have been a fiasco, setting back many small firms." It was also stated that "when solar reaches the stage that it's big business, the large manufacturers, i.e., Honeywell, will develop all the controls needed without spending tax dollars." Additional comments were "only applied research should be subsidized by the government" or "possibly implementation, evaluation, and modifications."

Question 19: Will present controllers provide adequate logic for future systems?

Overall, 27% responded "yes," 5% said "too complicated," 35% said "too simple," and 33% said "will require a microprocessor." Among distributors and installers, 44% answered "yes," 10% said "too complicated," 20% said "too simple," and 26% felt they "will probably require a microprocessor."

Of those who responded "yes," several said that "present controls are reliable, efficient, and adequate," and that "systems must be kept simple." Another comment was that "simple, even primitive systems appear cost reliable and cost effective. They need little new logic."

Among those who felt they are "too complicated," one commented, "I think simplification is in order," the feeling being that controllers are "too complicated for small systems."

Most felt that existing controllers are "too simple," especially for space heating and industrial applications, and that what is needed is "more data about systems 'health', i.e., how well it is converting solar energy." It was also stated that "built-in self-test and operational monitoring must eventually be applied to controllers for better quality and more reliable DHW and space heating systems." Other comments were that "small logic controllers ought to be sufficient" and that there are "4, 6, and 8 mode controllers under development."

Of those who feel microprocessors will be required, a typical comment was that "larger systems will probably require a microprocessor." It was stated that "a microprocessor based system may prove most cost effective for the commercial applications, providing flexibility, i.e., one controller design could be programmed for widely varying systems, detailed operation optimization, and, if desired, even data collection."

III. CONCLUSION

The survey was conducted during the first part of 1978. Since that time, various firms in the solar industry have incorporated some of the suggestions made by respondents into their services and product lines. Hardware is now on the market which includes the following features:

- 1) Outdoor temperature anticipation for thermostats
- 2) Control strategies designed specifically for heat pump interfaces
- 3) Increased output capability from single control modules and monitoring devices.

In addition, several manufacturers offer training courses for installers and the Solar Energy Research Institute is compiling a complete "controls Handbook" to guide designers and installers in selecting and applying the controls most appropriate to the system.

* * *

Questionnaire statistics and details of specific comments to the questions are available from Solar Control Corporation upon written request.

APPENDIX A

QUESTIONNAIRE MASTER LIST

Table A-1 gives a cross reference for the specific questionnaires that were mailed to manufacturers, installers and distributors, and architects and engineers. The questions that correspond to the left column follow in the same form they were on the three different questionnaires.

Table A-1
QUESTIONNAIRE CROSS REFERENCE

	Manufacturer	Installer & Distributor	Architect & Engineer
1	1	1	1
2	2	2	2
3	3	3	3
4	4		
5	5	4	4
6	6	5	5
7	7	6	6
8	8	7	7
9	9	8	
10	10	9	
11	11	10	8
12			9
13	12		12
14			13
15			14
16		11	15
17	13	12	16
18	14		
19	15		17

To receive results of survey: Name _____

Address _____

1. Your activity with solar controllers:

☐ Manufacturer	☐ Engineer
☐ Distributor	☐ Architect
☐ Installer	☐ _____

2. Type of system you deal with primarily:

☐ Space heat	☐ Pools
☐ Space cool	☐ Industrial process heat
☐ DWH heating	☐ _____
☐ Agricultural	

3. Is the system you checked above for:

- ☐ Single family residence
☐ Multi family residence or commercial

4. What type of temperature sensors are used with your controllers?

☐ Thermistor	☐ Transistor
☐ Thermocouple	☐ _____
☐ Diode	

5. Which type of system will show the greatest growth in the next five years?

☐ Space heat	☐ Pools
☐ Space cool	☐ Industrial process heat
☐ DWH heating	☐ _____
☐ Agricultural	

6. Existing control strategies are:

- ☐ Too simplistic
- ☐ Appropriate
- ☐ Too sophisticated

Comments _____

7. In their ability to maximize system effectiveness, present controllers:

- ☐ Leave much to be desired
- ☐ Are o.k.
- ☐ Couldn't be much better

Comments _____

8. Should controllers be inspected and certified:

For safety?

- ☐ Yes
- ☐ No

Comments _____

For performance?

- ☐ Yes
- ☐ No

Comments _____

9. Installation of present controllers is:

- ☐ Easy
- ☐ Manageable
- ☐ Too difficult or expensive

Comments _____

10. Maintenance service is:

- ☐ Readily available
☐ Marginal
☐ Very scarce or expensive

Comments _____

11. What are the major shortcomings of existing controllers? (Put a 1 by your first choice, a 2 by your second, etc.)

☐ Cost	☐ Expensive maintenance
☐ Limited control logic	☐ Size
☐ Appearance	☐ Power requirements
☐ Difficult to install	☐ _____

Comments _____

12. Should controllers have a user override capability?

- ☐ Yes
☐ No
☐ No opinion

13. What type of switching do you prefer?

- ☐ Solid State
☐ Mechanical Relays

Comments _____

14. Specify the features in order of importance that you look for in a controller. (Put a 1 in the most important, a 2 in the next most important, etc.)

☐ Cost	☐ Power requirements
☐ Ability to perform specified task	☐ Ease of installation
☐ Appearance	☐ Maintenance
☐ Lighted display	☐ _____
☐ Size	

15. Are presently manufactured controllers adequate for most present day applications?

☐ Yes

☐ No

Comments _____

16. Do presently manufactured controllers perform as claimed?

☐ Yes

☐ No

Comments _____

17. Please list any future areas where you feel there will be a need for new types of controllers.

1. _____

2. _____

3. _____

18. Should the development of new controllers be subsidized by the government:

☐ Yes

☐ No

☐ No opinion

Comments _____

19. Will present controllers provide adequate logic for future systems?

☐ Yes

☐ No, too complicated

☐ No, too simple

☐ Will probably require a microprocessor

Comments _____

Additional comments: