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Proceedings of the

Workshop on Solar Collectors For Heating and Cooling of Buildings

MASTER

New York City November 21-23, 1974

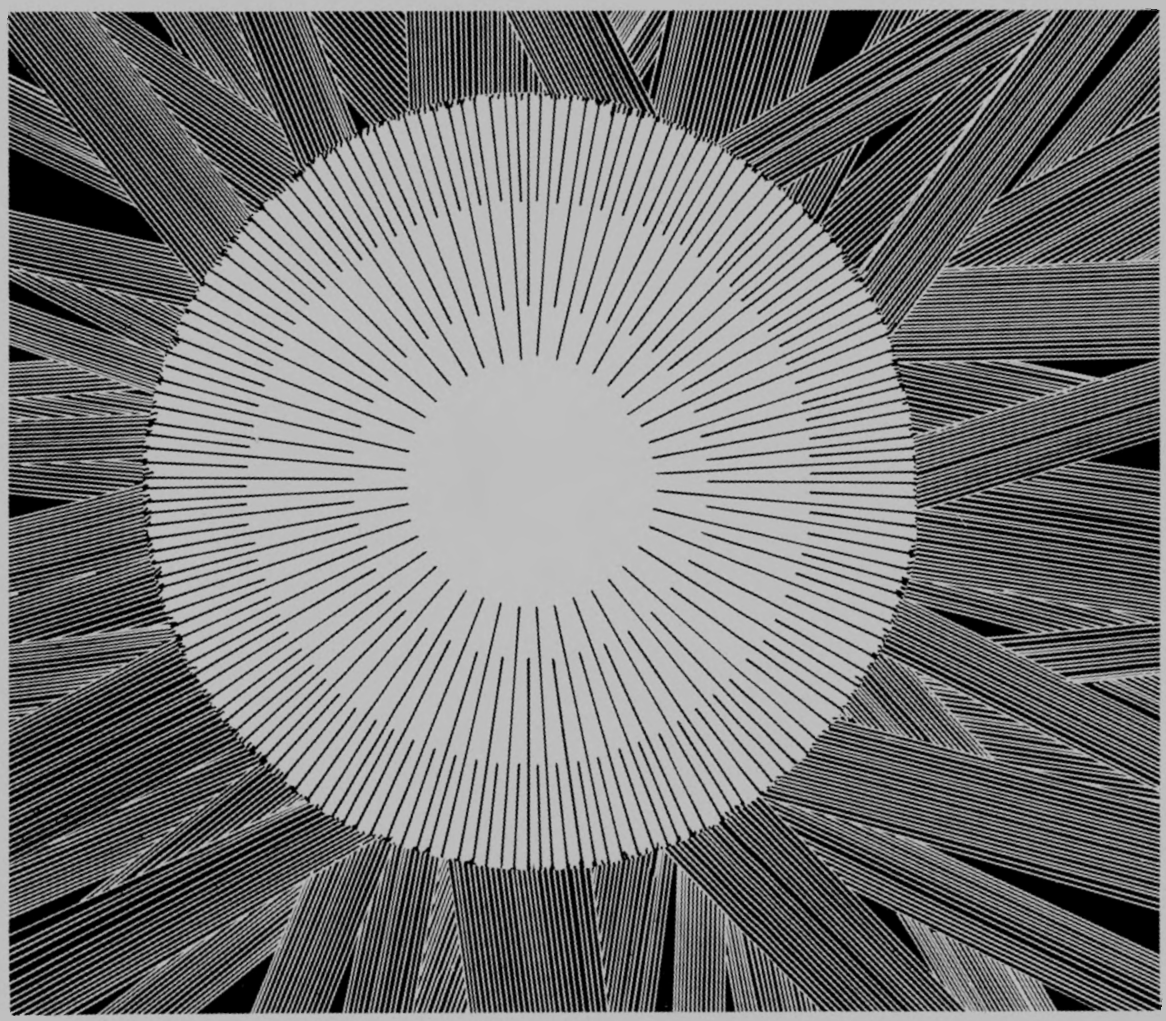
Sponsored by the

National Science Foundation
RANN – Research Applied to National Needs

Coordinated by

University of Maryland
Department of Mechanical Engineering

American Society of Mechanical Engineers
Solar Energy Division



Grant Number AER 74-24639

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Proceedings of the

WORKSHOP ON SOLAR COLLECTORS FOR HEATING AND COOLING OF BUILDINGS

New York City November 21-23, 1974

Held in conjunction with the Winter Annual Meeting of the
American Society of Mechanical Engineers

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May 1975

Proceedings Edited by
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Grant No. AER 74-24639

The contents of the presentations, and the opinions expressed in the discussions, are those of the Workshop participants and do not necessarily reflect the views of the National Science Foundation, University of Maryland, or American Society of Mechanical Engineers.

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The Editor gratefully acknowledges the very valuable assistance provided by Lloyd Herwig and Harold Horowitz of NSF/RANN in formulating the Workshop program and suggesting participants. Mr. Horowitz served as Program Manager for the Workshop grant. George James and Robert Miley of NSF/RANN were helpful in the preparation of these Proceedings. Redfield Allen, Frederick Morse, Francis DeWinter, and Anthony Iachetta contributed suggestions based on their experience in organizing previous Solar Energy Workshops. Marion Churchill and Carron Garvin of the ASME staff provided very helpful assistance with meeting arrangements and press relations. Faculty, staff, and graduate students of the University of Maryland Department of Mechanical Engineering assisted greatly at the Workshop. Sheila Tamches ably helped in organizing the Workshop and preparing the Proceedings. Members of the ASME Solar Energy Division Executive Committee and Advisory Committee served as Session Aides. The Session Chairmen and Facilitators were instrumental in keeping the Workshop program running smoothly, and their contributions are appreciated.

OTHER WORKSHOPS HELD UNDER THIS GRANT

NSF/RANN Workshop on the NBS Draft Standards
for Testing Solar Collectors
and Thermal Energy Storage Systems

Colorado State University, Ft. Collins
August 23, 1974

The purpose of this Workshop was to obtain input from Principal Investigators on NSF/RANN-funded projects pertaining to solar collectors and thermal storage devices. No Proceedings were issued, since the participants' comments were incorporated in drafting the Interim Reports:

NBSIR 74-635:	Method of Testing for Rating Solar Collectors Based on Thermal Performance
NBSIR 74-634	Method of Testing for Rating Thermal Storage Devices Based on Thermal Performance

The above reports are available from the Thermal Engineering Systems Section, Center For Building Technology, National Bureau of Standards, Washington, D.C. 20234

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INTRODUCTION

Since the upsurge of renewed interest in solar energy began in the early 1970's, several workshops devoted to solar heating and cooling of buildings have been held under the sponsorship of the National Science Foundation, program on Research Applied to National Needs (NSF/RANN): at Washington in March 1973, Los Angeles in February 1974, and Washington in June 1974. Invariably, questions were raised at these meetings about the types of solar collectors needed (and available) for solar heating and cooling systems, and there was usually not sufficient time to discuss these issues in any depth. It was therefore proposed to NSF/RANN that a workshop devoted exclusively to collectors for building applications be held in late 1974.

With the University of Maryland Department of Mechanical Engineering and the American Society of Mechanical Engineers Solar Energy Division acting as co-organizers, the Workshop was scheduled for the Week of November 18-23, to coincide with the ASME Winter Annual Meeting. Four solar energy sessions were planned for the ASME WAM (held at the Statler Hilton Hotel): "Solar Heating and Cooling of Buildings" and "General Solar Energy Applications" on Tuesday (both sponsored by the Solar Energy Division), and "Thermal Storage" and "Heat Transfer in Solar Energy Technology" on Wednesday (both co-sponsored by the Solar Energy and Heat Transfer Divisions). The Workshop was therefore scheduled at the New York Hilton Hotel for Thursday and Friday, with a morning session on Saturday needed to complete the program.

In keeping with the NSF/RANN objective of promoting information exchange and communication between researchers and representatives of architectural, engineering, manufacturing, marketing, users', and governmental groups, the Workshop's purposes were set as follows:

1. To assess the current state of collector development;

2. To examine new design concepts;

3. To identify for NSF/RANN and other government agencies the most promising directions for further research and development;

4. To present results of collector performance tests in NSF-funded advanced research projects and state-of-the-art projects;

5. To present the proposed standards, formulated by the National Bureau of Standards, for testing solar collectors, and to generate suggestions for changes and improvements;

6. To compare different numerical collector models; and

7. To present and explain the programs of NSF/RANN and other government agencies in the field of solar collector development.

The Workshop consisted of three different types of activities: formal presentations of 10-15 minutes each by researchers, industry representatives and government spokesmen; panel discussions by collector manufacturers and collector users; and, on Friday evening, meetings of Working Groups on six specific topics. The complete Workshop program is included near the end of the Proceedings. Presenters, panelists, and Working Group members were invited to participate based on their present or past experience in the solar collector field. The Working Groups were intentionally kept fairly small, both because of the space limitations of the meeting rooms, and to promote an informal interchange among group members.

Each session had a chairman and a facilitator. Since the amount of time for questions and discussion of each session was relatively limited, Workshop attendees were requested to utilize the printed question/comment forms as much as possible. The facilitator screened the written questions to eliminate duplication, and presented the most relevant ones to the presenters or panelists during the discussion period. A coffee break was scheduled (where possible) between the presentations and the discussion period to allow the facilitator time to assemble the questions.

No written material was required from participants before the meeting, although a short written summary with figures was requested shortly afterwards for the Proceedings. The entire Workshop was tape recorded (with the exception of the Working Group meetings), although the transcript was utilized primarily for the discussion periods. Copies of the written questions and comments (both asked and unasked) were submitted to the participants for their written replies. These, plus edited versions of the taped questions and answers, form the basis of the published discussion. In the interests primarily of prompt publication, and secondarily, economy, the participants' typed summaries have not been set into type but have been photo-offset as submitted.

The registered attendance of just under 500 attests to the high level of interest in solar heating and cooling. The interest and enthusiasm of the participants and attendees was evident throughout all three days, and helped ensure the success of the Workshop. A list of registrants and their addresses is included at the end of the Proceedings.

SESSION 1

FLAT PLATE LIQUID HEATING COLLECTORS

WELCOME AND OPENING REMARKS

Lloyd O. Herwig
Director, Advanced Solar Energy Research and Technology
Division of Advanced Energy Research and Technology
National Science Foundation
Washington, D.C. 20550

I consider it a privilege to welcome you to the opening sessions of this "Workshop on Solar Collectors for Heating and Cooling of Buildings." This is the fourth heating and cooling workshop that has been sponsored during the past two years by the Research Applied to National Needs Directorate of the National Science Foundation.

The first was a general meeting covering component, subsystem, and system work and was held in the Washington area in the spring of 1973. A second workshop was held in February of this year in Los Angeles with emphasis on solar cooling components and systems. In June of this year, the results of three studies of the market potential and viable applications of heating and cooling systems were presented, the so-called Phase Zero studies.

Now we are gathered together for the third time this year (the fourth heating and cooling workshop) to discuss another very important topic--solar collector technology. You represent a very important and diverse group of people who are actively involved in reducing the time to obtain large-scale implementation of reliable, cost-effective, commercially-available heating and cooling systems for all types of buildings in a wide variety of geographic locations.

In welcoming you, it is a great pleasure to recognize the efforts of the University of Maryland staff, led by Professor Steve Sargent, in organizing this conference and providing for the fine program and arragements.

During the next few minutes, I would like to discuss briefly the following topics:

- The National Solar Energy Research and Technology Program in the Heating and Cooling area.
- The impact of recent legislation on the organization and implementation of solar energy research and development.
- The establishment of the Energy Research and Development Administration (ERDA); the passage of the Solar Heating and Cooling Demonstration Act of 1974; and, most recently, the passage of the Solar Energy Research, Development, and Demonstration Act.
- The final reports of Project Independence, a 6-month concerted study of the Nation's energy problems, resources, and potential strategies.

As most of you already know, the Federal funding for solar energy research and technology has grown from a few million dollars per year in

the early 1970's to $50M for FY 1975, which ends June 30, 1975. For the past several years, the National Science Foundation has had the lead Federal role for solar energy research and technology--but that is now in the process of being changed as I will discuss in a few minutes. In the role of lead Federal agency, the NSF staff has organized and worked cooperatively with staff from more than 20 other Federal agencies in formulating a relatively detailed National Solar Energy Program Plan for the next 5 to 10 years. This Plan has been presented to the Office of Management and Budget (OMB) for information, but it has not been officially accepted. However, this basic R&D plan continues to be pursued vigorously.

FY 1975 represents the first year in this new Plan. Of the $50M solar energy budget, $17M, or more than one-third of the total funds, is allocated to the highest priority program area--the heating and cooling of buildings that has now been extended to include agricultural applications.

At the present time, there are about 45 active heating and cooling research projects and about 15 system experiments. The research projects include about a dozen projects on newand improved solar energy collector components and subsystems. The system experiments have been established to gain performance data and operating experience with state-of-the-art systems under actual environmental and user conditions. These include five school heating and cooling experiments residential and commercial building experiments, agricultural experiments, and others. You will hear more about these experiments in the Saturday morning session.

Solar energy collection appears to be the most crucial subsystem in developing economical systems for heating and cooling buildings. It is identified as the driving technological problem affecting both a system's performance and its economic viability.

One sobering realization of its importance comes indirectly in realizing that the average sun's energy falling on a square foot of the Continental United States is worth about 50¢ per year based upon a 50 percent collection efficiency and an assumed energy value of $2 per million Btu's (oil at $12 per barrel). An annual average U.S. insolation of 1500 Btu's per square foot per day over a 365 day year leads to somewhat more than 500,000, or one-half million, Btu's in the course of a year. With 50% efficiency, a square foot of collector can thus collect and transfer only about one-fourth of a million Btu's per year. At $2 per million Btu's, this is 50¢ worth of energy per year, which must justify the investment. If an installed collector and its associated system cost $5 per square foot of collector, it would require more than 10 years to recover the investment. At the present time, an installed solar heating system costing $5 per square foot of collector would represent a real breakthrough.

More optimistically, the energy delivered at the point of need, namely a building, is worth much more than $2 per million Btu's, particularly if it is replacing electric resistance heating at 2 or 3 cents per kilowatt hours or about 6 to 9 dollars per million Btu's. In any case, this working audience has a continuing large challenge to seek viable economic solutions.

The legislation establishing ERDA was signed into law in early October, and ERDA is to be activated within 120 days--meaning before the middle of February. The ERDA is designated to bring together and direct Federal

activities relating to research and development on the various sources of energy. The organizational structure includes an administrator, deputy administrator, and six assistant administrators, including an assistant for solar, geothermal, and advanced energy systems. All are to be appointed by the President with the advice and consent of the Senate. The AEC will become one of the six units in the ERDA organization and will, of course, be responsible for nuclear energy.

To date, only the Administrator has been nominated and no Senate action has been taken. In the solar, geothermal, and advanced energy systems unit, no ERDA assistant administrator or staff has been designated. The responsibility for continuing the National Solar Energy Program remains with NSF until an ERDA staff is identified to received transferred projects or program funds. The NSF staff is continuing to implement this year's entire program until an ERDA staff is operative. At that time the lead Federal role in solar energy is expected to be transferred to ERDA.

However, the current Federal reorganization plan in solar energy is expected to result in a significant NSF responsibility in the overall program; namely, responsibility for advanced research and technology in each of the six current program areas. Responsibility for all proof-of-concept experiments (that is, pilot plants), demonstrations, and prototype plants along with the immediate research and development needs will go to ERDA. This transfer of responsibility also requires the transfer of a large majority of solar energy funding--probably more than 80% in FY 1976. Staff positions are to be transferred to ERDA from the present NSF solar energy and geothermal energy quotas.

Although there can be no definite plan for ERDA staff in solar energy until an organizational structure is developed, it is expected that some present solar energy staff at NSF and AEC will be given the opportunity to be transferred to ERDA. Let me restate that changes will be taking place in the near future, but that in the meantime, the solar energy program will continue to be implemented by the NSF.

The Heating and Cooling Demonstration Act of 1974 was signed into law in September, 1974. Sixty million dollars has been authorized to carry out the Act over the next five years. However, no funds have been appropriated. HUD has the responsibility for residential demonstrations and for data gathering and information distribution. NASA has responsibility under the Act for procuring state-of-the-art systems. Initial planning is approaching completion. The status of planning will be explained in a workshop meeting scheduled for Friday afternoon.

As many of you know, during the summer the Federal Energy Administration initiated Project Independence Blueprint (PIB), a substantial national study of the Nation's energy status, resources, and potential strategies along with estimates of potential alternatives and impacts. About 20 detailed studies, each under the direction of a lead Federal agency, were undertaken for various energy resources and problems.

The FEA solar energy study was led by NSF and undertaken in conjunction with staff from about 20 other Federal agencies. The PIB solar energy report along with the other reports have now been completed. An overview report has been written by the FEA staff. These reports have been presented to the

President and are now available to the general public. They may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. The PIB Overview Report and the Solar Energy Task Force Report may be obtained using the following identifications:

Project Independence Report - Executive Summary and Overview Section
Stock Number 4118-00029
Price $8.35 (337 pages)

Project Independence Blueprint
Solar Energy - Task Force Final Report
Stock Number 4118-00012
Price $8.00 (estimate) (300 pages)

The Project Independence Project Reports include a total of 22 reports plus transcripts of 10 public hearings.

I am looking forward to a very fruitful interchange with you of knowledge and ideas throughout the next three days of this workshop. Thank you.

DISCUSSION

Question (Richard H. Braasch, Sandia Laboratories): Why is it necessary for solar energy to compete economically with a heavily subsidized item such as petroleum products without at least equivalent Government support?

Answer (Lloyd O. Herwig, National Science Foundation): I do not think we are ready to address the issues of solar energy in a competitive sense with other energy sources. As the solar energy technologies are developed, there will be incentives to install these systems where they seem to be viable. We need to work toward economic viability as we develop these systems. We must realize that costs are shifting, and costs of the environmental aspects will be incorporated more and more—in solar systems, which have a few problems in themselves, as well as in fossil fuels and nuclear resources.

We would like to approach incentives from the point of view that incentives will bring on an earlier reduction in the need for other types of fuels through the use of solar energy systems. We would not like to think that incentives have to go on indefinitely in order to maintain solar energy systems. Let us use incentives to speed up the introduction of solar energy systems, but let us not depend on incentives to keep them in business.

In our FEA report we took two approaches to implementing solar energy technologies. One is business as usual. Whatever is commercially practical will be implemented as other business opportunities are developed. The second approach is to accelerate development or implementation through tax rebates, investment credits, and other ways to encourage the introduction of solar energy.

In our own analysis, these two approaches could result in solar energy systems' replacing a million barrels a day of fossil fuels by 1985—three or four times the potential of oil shale, coal gasification, and liquefaction in the same time frame. We want to make that happen, for a million barrels a day is a lot of oil.

52,070

Performance of the Fauquier High School Solar Heating System

George Szego
InterTechnology Corporation
Warrenton, Virginia 22186

I Design Summary

Collector area requirements were based upon meeting 100% of the space heating load under average weather conditions for the month for January. This led to a required collector area of 2,440 square feet. The collector area actually installed is 2,415 square feet, tilted at 53^{o} to the horizontal, and facing due south. Figure 1 is a picture of the complete installation. Two transparent covers over the absorber plates are required in the northern United States for reasonable heat collection efficiencies. The glazings used are double strength window glass (DSB) for strength and durability. The absorber plate is of aluminum and is coated with a selective coating with $\alpha/\varepsilon = 3$ and $\alpha \simeq 0.93$. The plate has one inlet and one outlet for the flow of fluid and has tubes of approximately 0.2 inches hydraulic diameter spaced 2.4 inches apart. This design leads to about a 96% plate efficiency factor.

The total number of collector boxes is 105. As now set up, three boxes are employed in series and thirty-five of these three box units are connected in parallel. The flow rate of water varies from about 9 to 14 $lb_m/hr\text{-}ft^2$ of collector area depending upon the mode in which the system is operating. The circulation pump requires an input of 1.13 KW.

Two independent hot water tanks, each with 5,000 gallons capacity, have been employed for better storage utilization of the solar energy available on any given day. When the tanks are fully charged, they can meet the heat requirements for 6 to 10 consecutive days without sunlight, depending upon the severity of weather. The tanks, of reinforced concrete, are buried underground and have thermal insulation on all sides. On an average day, the heat loss from the tanks is equivalent to about $1^{o}F$ drop in water temperature, not including heat demands from the classrooms.

The control system utilizes temperature differentials for control signals and operates in the following four basic modes:

A. Water goes from collector to living space in a closed loop until the heat requirement is satisfied. This mode of operation is used only if the tanks are relatively cold, solar heat is available and the classrooms require heat.
B. Water goes from the collector to the tank it came from.
C. Water goes from the collector to living space and back to tank.
C. Water from the tank goes to the living space and back to the tank.

In practice, we have seven modes of operation. Mode A is independent of the number of tanks, but modes B, C and D are duplicated for each tank, giving a total of seven modes.

Since no antifreeze is used because of excessive costs, corrosivity and poor thermal performance of that liquid, a dump mode has been provided. Whenever absorber plate temperatures drop below $40^{o}F$, all the water in the system drains into one of the tanks, always the same one. A corrosion inhibitor is maintained at a given concentration and pH level in the water.

II Analysis

Certain sets of assumptions are implicit in any mathematical formulation of a physical problem. The following assumptions were made in the performance analysis of flat plate solar collectors.

A. The effective transmittance-absorptance product is a constant and is independent of the angle of incidence.

B. The emissivities of the two glass cover plates for long wavelength radiation is constant.
C. During daylight hours, sky temperature for radiant heat transfer is the same as ambient temperature.
D. The system is at steady-state.
E. Thermal conductivity, specific heat, and other properties of water are independent of temperature.
F. The system is at atmospheric pressure, i.e. the tanks are vented.

On the basis of the above set of assumptions, a set of equations analogous to Zarem and Erway[1] were obtained. Solution of these equations on a digital computer gave the performance characteristics of our design and the results are presented in Figures 2, 3 and 4.

III Experimental Results

Figure 4 is a theoretical curve of the overall collector heat loss coefficient as a function of the collector plate temperature for the conditions mentioned with the curve. Figure 5 is a comparison of the theoretical efficiencies with the results obtained experimentally. Ideally, all the points on Figure 5 should lie on a 45^{o} line. The points were selected randomly for comparison to cover a wide range of average plate temperatures.

Figures 6 and 7 are performance plots of the flat plate collectors for operation on April 18 and October 11, 1974, respectively. These two dates had similar conditions but are widely separated in time. The plots present the ambient temperature, the solar flux on collector surface tilted at 53^{o} and facing south, the instantaneous average tank temperature, and the instantaneous heat collection efficiency as a function of the time of day. A point of inflection in the curve for instantaneous average tank temperature exists because solar flux goes through a maximum at solar noon.

(1) Zarem, A.M., and Erway, D.D., "Introduction to the Utilization of Solar Energy", McGraw-Hill Book Company, Inc., New York, 1963

Following is the summary of collector performance on April 18 and October 11, 1974:

	April 18	October 11
Average inlet temperature, ^{o}F	153	143
Average ambient temperature, ^{o}F	66	70
Mass flow rate of water, $lb_m/hr\text{-}ft^2$	13.0	12.8
Solar energy incident on the collector, $Btu/ft^2\text{-}day$	1520	1300
Total collector area in use, ft^2	2415	2001
Total energy incident on the collector, Btu/day	3.67×10^6	2.60×10^6
Temperature rise of water in the tank, ^{o}F	38.4	27.9
Mass of water in the tank, lb_m	42600	42600
Heat capacity of water storage tank, $Btu/lb_m\ ^{o}F$	5000	5000
Q_c = Total heat collected, Btu/day	1.83×10^6	1.33×10^6
Efficiency, integrated over the day	0.50	0.51
$\int (A_c)\ (\dot{m})\ C_p \Delta T(time)$, Btu	1.74×10^6	1.32×10^6

The last quantity tabulated is the integrated heat collection over the whole day. Ideally, this integrated value should be equal to Q_c but is different from it because of random errors in the data measurements. For April 18, the difference is 5% and it is less than 1% for the October 11 data, well within the precision of the measurements.

Besides the above data, some dry plate temperature data were also obtained. For example, a temperature of $315^{o}F$ was measured on August 15 at 1350 hours when the ambient temperature was $95^{o}F$ and solar flux on the collector was 215 $Btu/hr\text{-}ft^2$

IV Conclusion

The Fauquier High School solar heating system has worked reliably for over a year and has heated 5 buildings for the better part of 2 heating seasons. Virtually no use of the original heating systems was needed. There has been no significant vandalism experienced. The system is also useful as a laboratory for the school's science classes and for the generation of extrapolable design experience and data. A fuller report of the construction and operation of the system is available from the U.S. Government Printing Office: "Solar Energy School Heating Augmentation Experiment."

The average performance of the system has exceeded the design target of 50% efficiency by a comfortable margin.

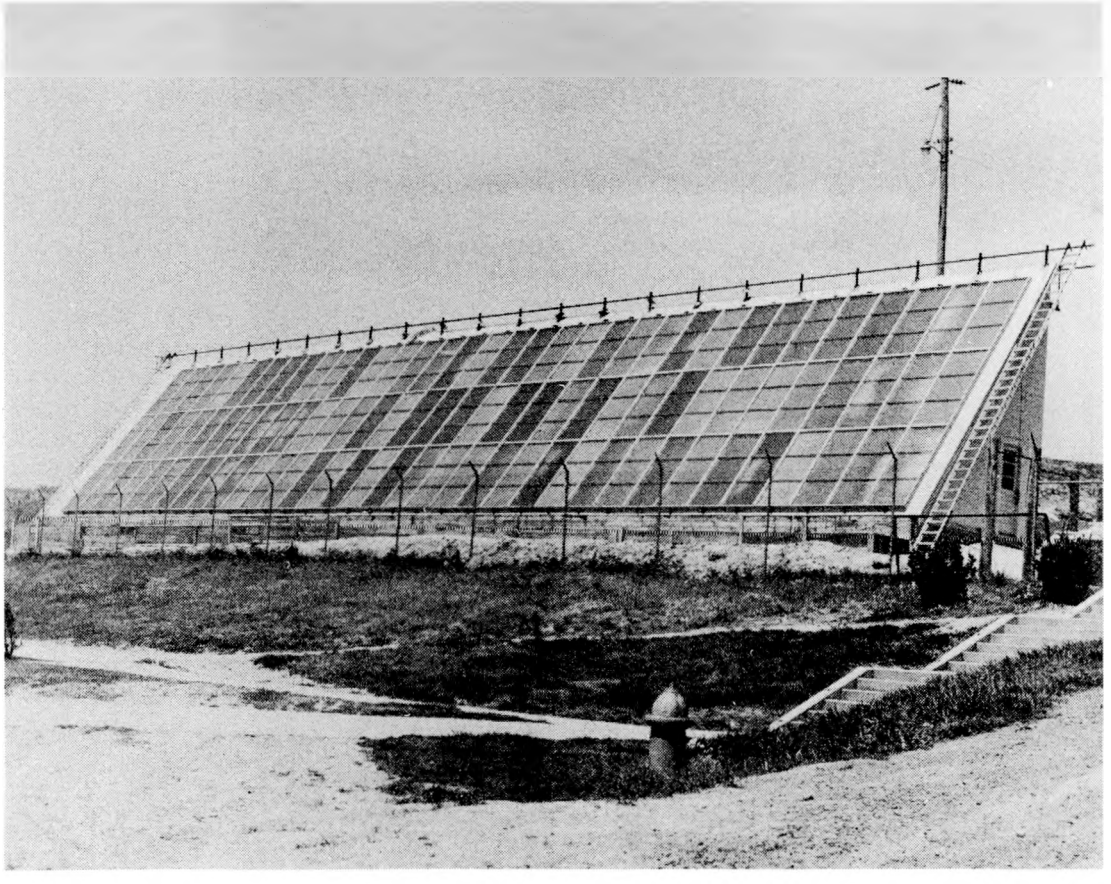


Fig. 1 – Collector Array

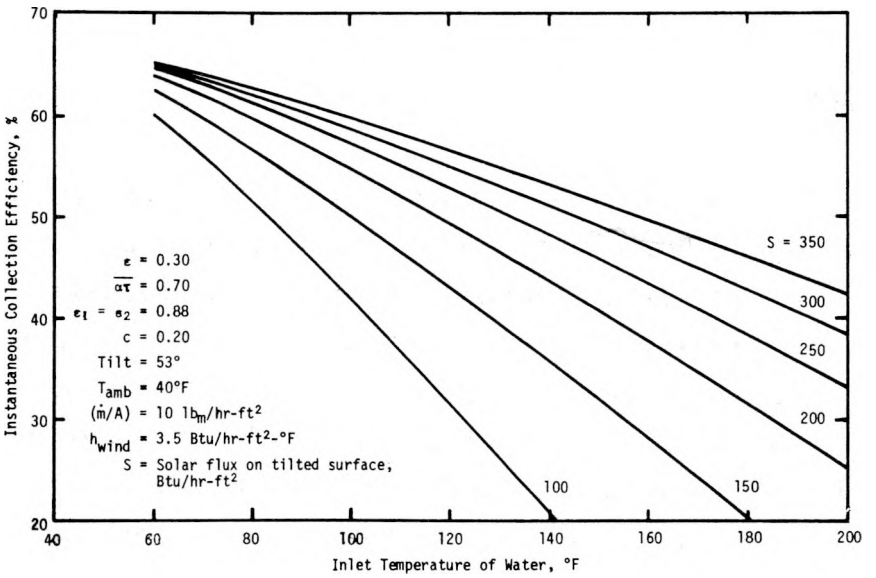


Fig. 2 – Variation of Instantaneous Efficiency with Inlet Temperature for Constant Solar Flux

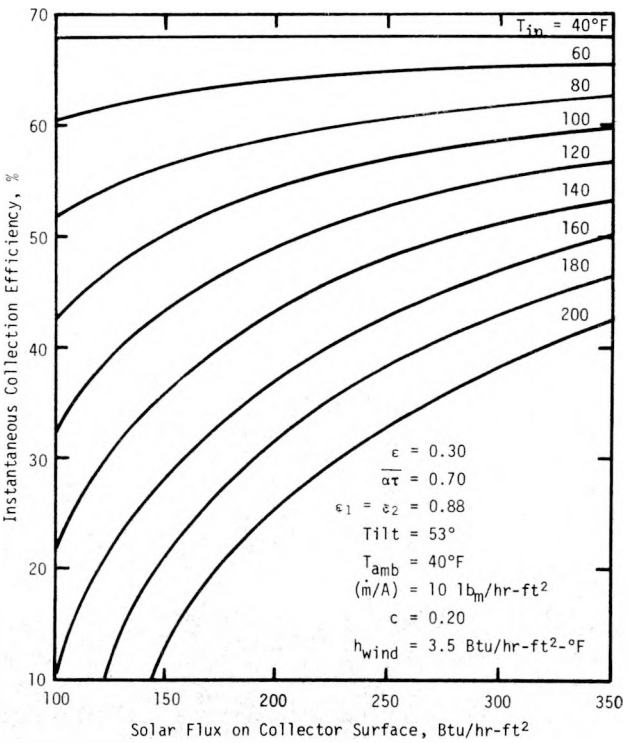


Fig. 3 – Variation of Instantaneous Efficiency with Solar Flux for Constant Inlet Temperature

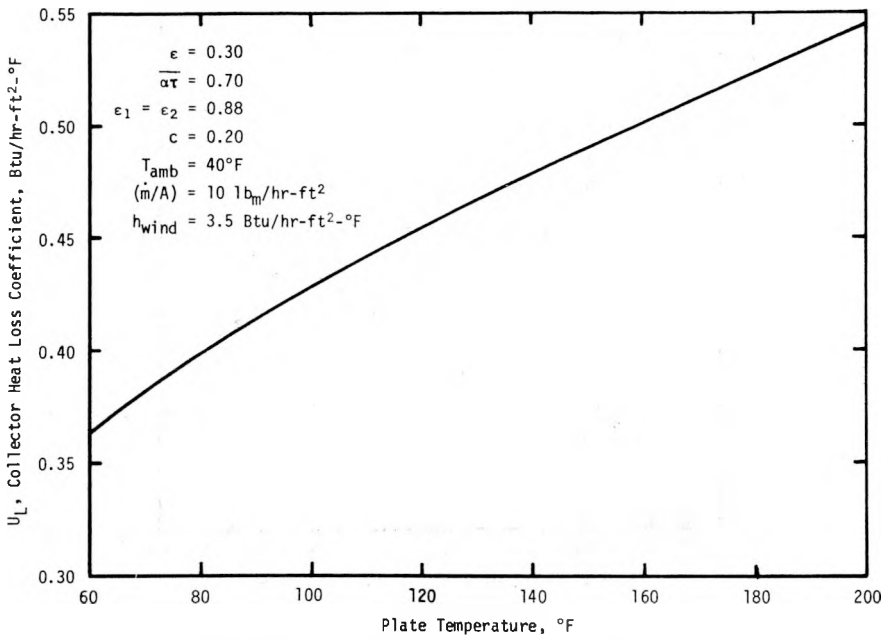


Fig. 4 -- Theoretical Heat Loss Coefficient

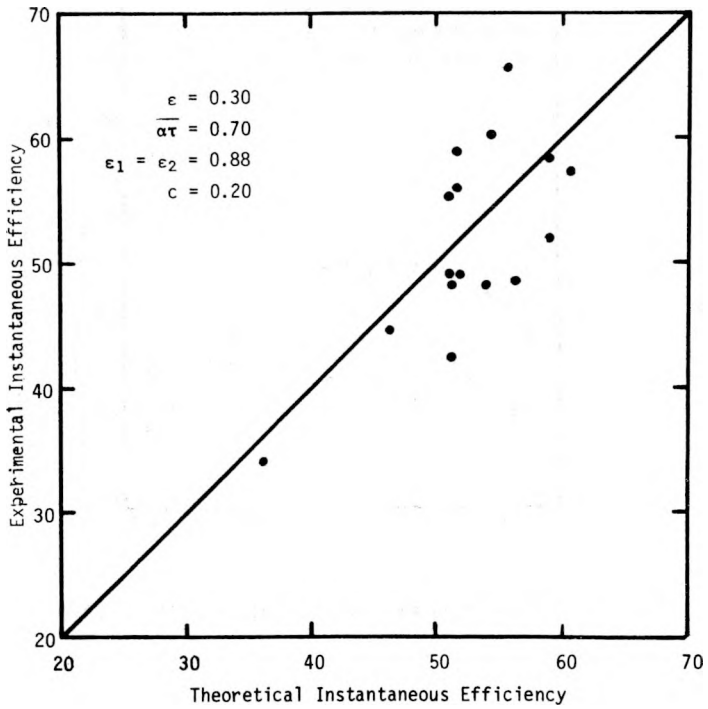


Fig. 5 -- Comparison of Experimental with Theoretical Efficiencies

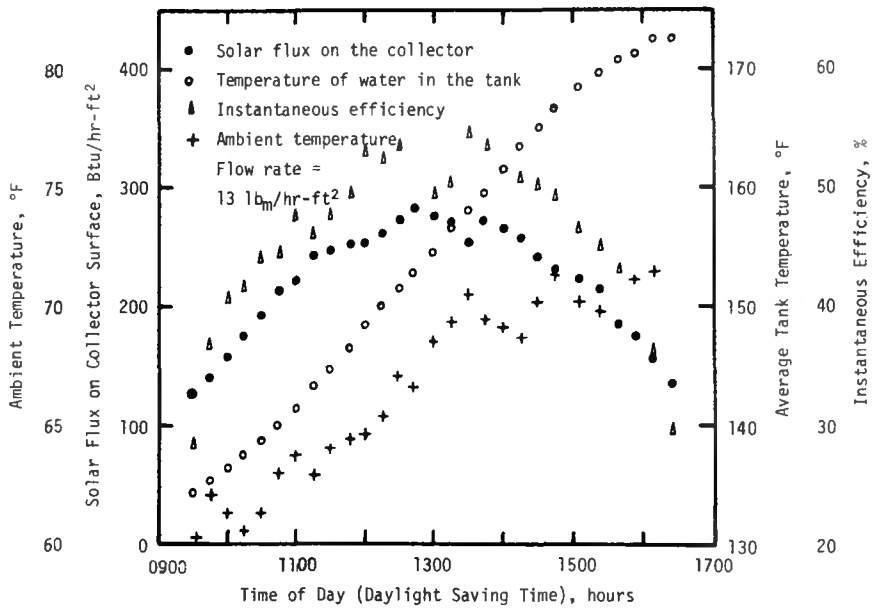


Fig. 6 — ITC Collector Performance on April 18, 1974

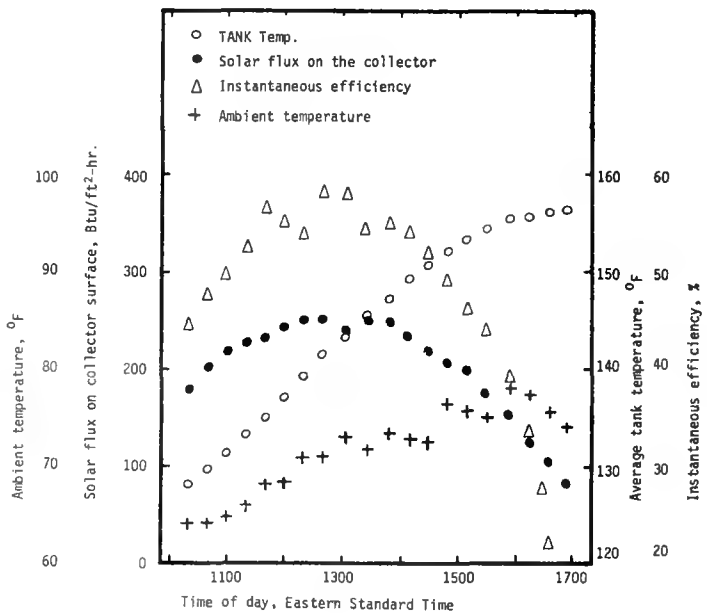


Fig. 7 — ITC Collector Performance on October 11, 1974

DISCUSSION

Question (Richard LaRosa, Hazeltine Corporation): How did you get the water to dump? Are all lines sloped to drain by gravity?

Answer (George Szego, Inter Technology Corporation): By gravity is correct. Also, we open an air vent at the top to prevent vacuum holdup. The system drains in 80-90 sec.

Question (Donald L. McClenahan): How often does the water have to be tested to be sure the inhibitor is effective?

Answer: The pH is checked about weekly.

Question (Mr. McClenahan): Has aluminum hydroxide developed in the water?

Answer: Only a trace of aluminum: much less than 1 part per million.

Question (Frank DeWinter, Altas Corporation): The 12 days' of storage seem to be much more than most researchers have been able to justify economically. Why were 12 days of storage used?

Answer: We wanted to explore the thermodynamic characteristics of two tanks rather than one. These projects were not economic; they were experimental. Our objective was to investigate areas not permitted under economic pressures.

Question (Richard L. Field, USN Civil Engineering Laboratory): Was auxiliary heating used?

Answer: The original electric-oil system is still in place. It was used very little in over 1 year.

Question (Mr. Field): Have you received any trouble from aircraft and pilots due to the reflection off the collectors?

Answer: No.

Question (Mr. Field): Why is the surface of the collector warped?

Answer: The collector is not held down in order to allow freedom for expansion; the warping is insignificant.

Question (Mr. Field): Are cost data on construction available?

Answer: Yes. See report GPO 038-000-00204.

Question (Mr. Field): Have you observed any corrosion, scaling, or deterioration of Roll-Bond®?

Question (Donald L. McClenahan, State University of New York, Albany): What problems have been experienced with aluminum Roll-Bond® collectors?

Answer (to both preceding questions): No significant corrosion has been experienced.

Our primary source of leaks has been in the steam hose clamp area, where there is a slight misalignment. The only aluminum leak we have experienced in our collector—which consists of 105 3- by 8-foot panels—has been a case of mechanical stressing at the weld where the nipples are heli-arc welded to the Roll-Bond®. We have had one plate failure out of 105. At the moment, our experience is good. We have not monitored aluminum ions in the tank water, but we have not experienced any wide-scale leaks. We have had very few leaks. There were leaks

experienced in the concrete tank, through the epoxy seal around its sections. We have used a proprietary coating to control that leak problem and have been running now for about 2 months with no tank leaks.

Question (Dan S. Ward, Colorado State University): Has the "dumb sequence" been operated? Did it drain effectively? Was there any indication of freezing?

Answer: Yes, the sequence has been operated and it drained effectively. Over 50 freezes have been experienced with no freezing of the collectors. Deliberate freezing warped the collector, but no breaks were experienced.

52,071

NORTH VIEW JUNIOR HIGH SCHOOL FLAT PLATE LIQUID HEATING COLLECTORS

BY: GLEN L. MERRILL

Honeywell Inc.
Systems and Research Center
2600 Ridgway Parkway
Minneapolis, Minnesota 55413

In January 1973, Honeywell Inc., Systems and Research Center undertook the design, development and installation of a 5000 square foot solar energy system to be located at North View Junior High School, Osseo School District located in Brooklyn Center a suburb of Minneapolis, Minnesota.

The general design of the collectors consists of liquid-cooled steel plates coated with selective absorbing coatings and enclosed in an insulated steel housing which is covered by two transparent windows, one glass and one Tedlar. Figure 1 is a corner section of a typical collector. Shown are the glass cover, Tedlar sheet, absorber plate, insulation, and the steel housing with the various structural assemblies.

The outer housing is composed of 18-gauge, cold-rolled steel 36 inches wide, 96 inches long and 6 inches deep. The housing is formed from a single sheet of steel in a press brake and welded at the corners. Internal brackets are welded to the housing for absorber mounting supports. In addition, channels are spot welded to the housing sides for support of the Tedlar sheet. Four access holes are provided for the plumbing and six additional holes are for maintenance and installation.

Hat sections of steel are formed and welded to the back of the housing for stiffening and to provide support for collector suspension on the support structure. Figures 2 and 3 show the housing design details.

The absorber panel itself is pictured in Figure 4. The unit consists of two 25-gauge, 1020 cold-rolled steel sheets 31.75 inches wide by 46.5 inches long with flow passages formed into the sheets. One sheet carries 0.250 inch x 0.050 inch deep grooves on 2-inch centers for basic heat transfer flow. The other sheet is formed to provide a 2.0 inch x 2.0 inch manifold at one end with a 0.50 inch x 0.50 inch manifold at the other end. The two sheets are assembled by spot and seam welding to form a parallel flow panel with large manifolds and small heat transfer channels. Formed steel tubulations on each corner permit connection by automotive type hose of a series of panels to form an array of parallel collectors with small vertical heat transfer passages. The design minimizes the effects of nonuniform flow through the panel assembly.

The final design of a complete collector used two absorber panels assembled within a unit for fabrication conveniences. The two panels are connected by small hoses between the smaller manifold tubulations and are attached to mounting brackets by insulating nylon washers.

Additional design features include a frame which is placed over the outside edges of the glass cover which is 3/16 inch X 34-57/64 inches x 95 inches tempered glass. A sealant tape is used on both sides of the cover near the edges. Figure 5 shows the frame and glass assembly. Insulation is 3.5 inches of fiberglass across the back of the collector and along the sides to reduce edge losses. Figure 5 also shows the Tedlar sheets and frame installed in a typical collector. Collector sizing of 5000 square feet of absorber area dictated the fabrication of 246 individual assemblies which were then transported to and erected on the site.

The collector support structure was fabricated from square structural steel tubing 3 inches x 3 inches x 3/16 inch. Three rows of support structure 21 feet apart were needed to support the 246 collectors with each row 256 feet long and divided into two sections for a total of six sections. Erection of the structure consisted of boring 180 holes on 9-foot centers and then cementing in place the vertical support members. The vertical members were then cut to a 55-degree angle. Longitudinal

tubes were then welded to the cut posts forming a pair of rails upon which the collectors could be placed. Additional cross bracings of 1-1/2 x 1-1/2 x 3/16 angles were added to each pair of posts. Figure 6 shows a typical cross section of a pair of post supports while Figure 7 shows the structure with the panels mounted.

The completed collectors were placed on the rails and moved into position on small rollers. Hoses were connected at the top and bottom manifolds to complete the assembly. The structure itself is designed to withstand 90 mph wind loads with the collectors in place. Figure 8 shows the complete solar collector array.

The system developed leaks around the large manifolds which form the upper and lower headers in each row. A fix utilizing steel tubes and silicone "O" rings was developed. Figure 9 shows the assembly which was installed between the headers of each collector module. The system was back in operation within a month as of the time of this writing there has not been any detectable leaks.

System operation consists of pool air heating, pool water heating, domestic water heating and storage tank charging. System efficiencies have averaged between 35% and 55% depending upon the operational mode. Figures 10 and 11 are typical plots of the data that is being compiled on a daily basis. During the month of October 1974, the system collected about 70 million BTU's for an average efficiency of about 45%. This represents about 15% of the energy consumed during the month.

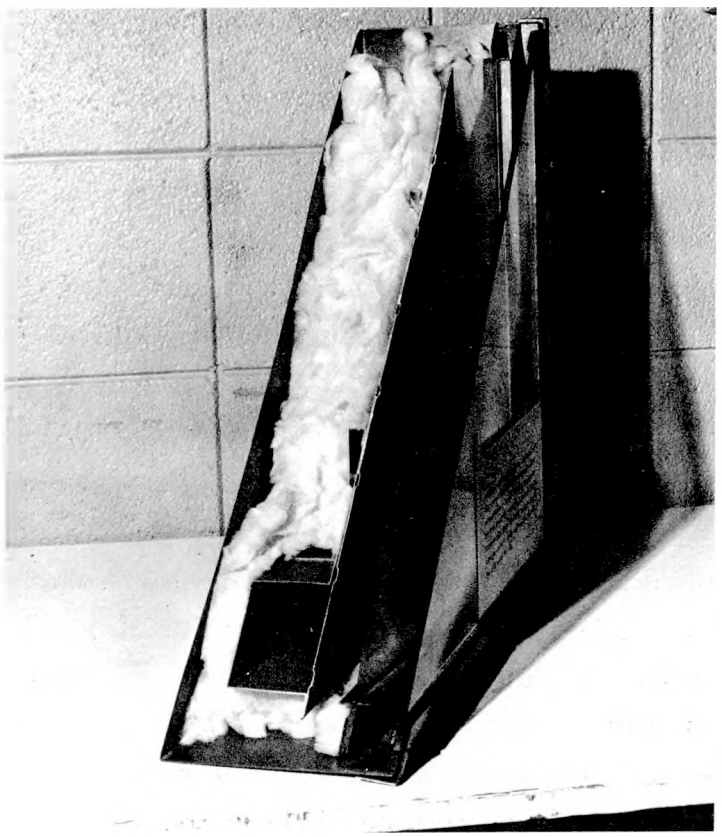


Fig. 1 – Collector Corner Section

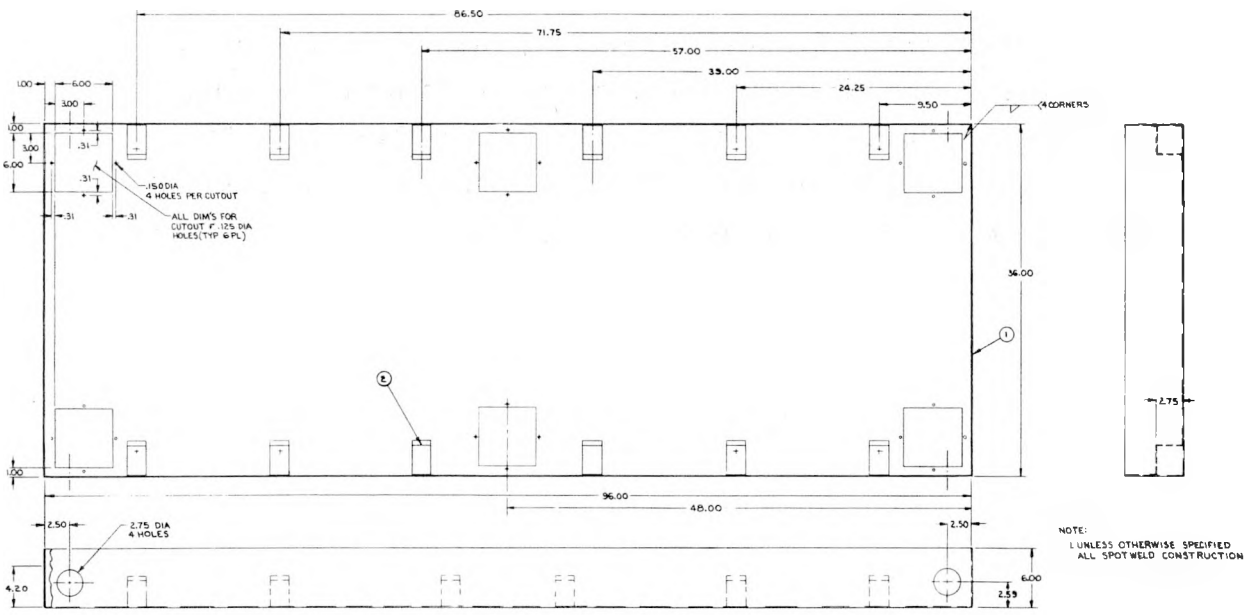
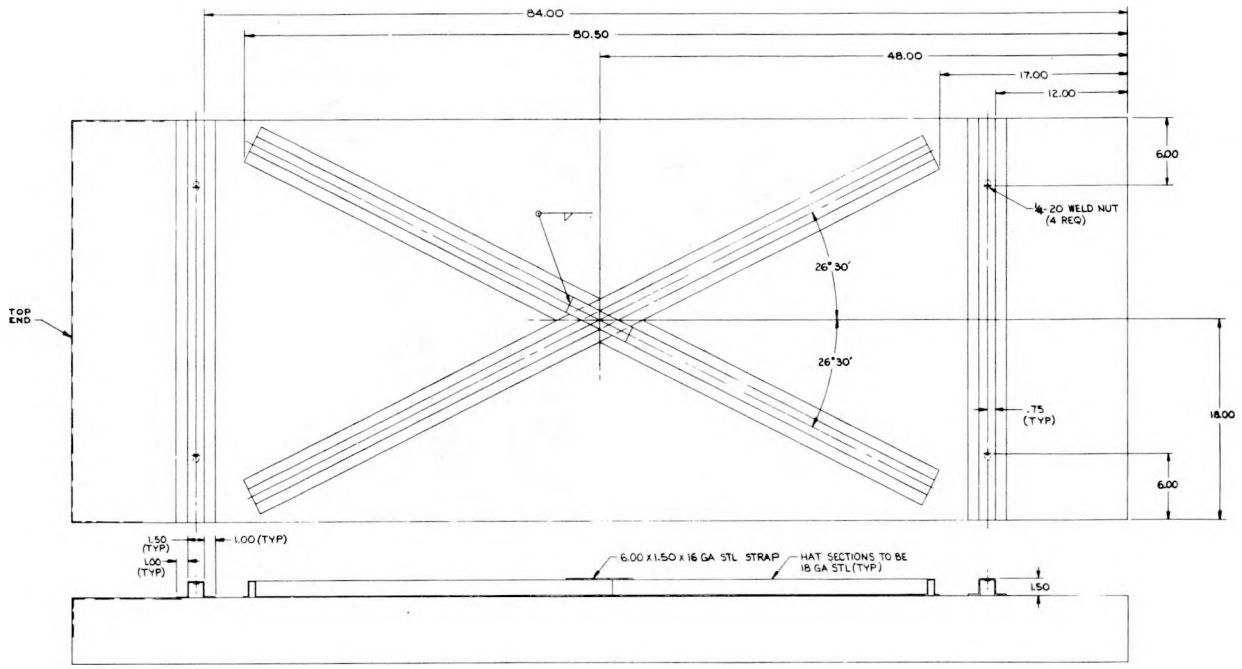


Fig. 2 – Collector Housing, Front View



NOTE:
1. UNLESS OTHERWISE SPECIFIED ALL SPOTWELD CONSTRUCTION

Fig. 3 – Collector Housing, Rear View

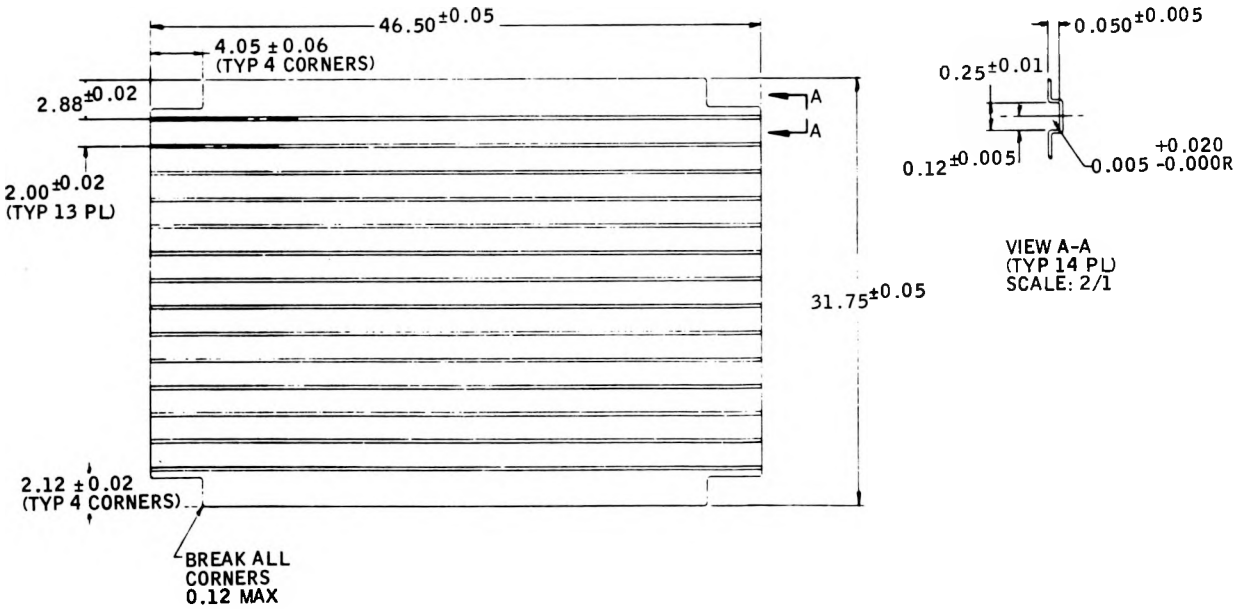


Fig. 4 – Absorber Panel

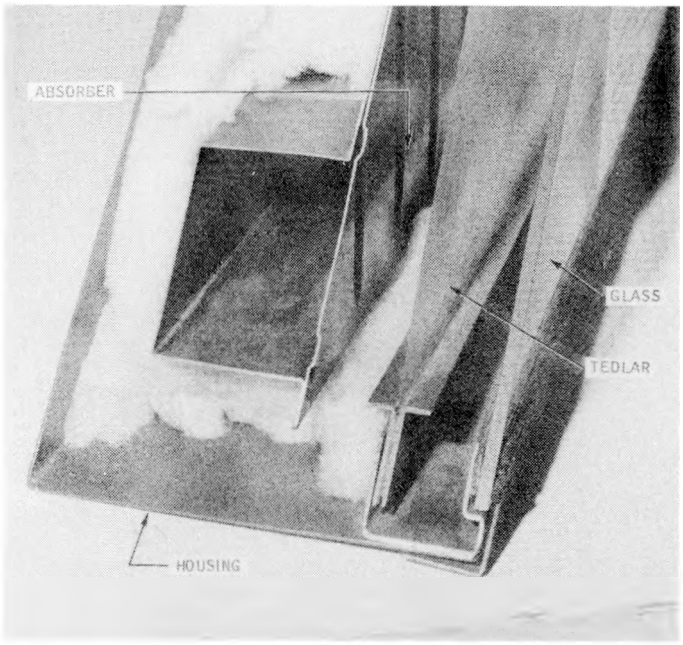


Fig. 5 — Solar Collector Section

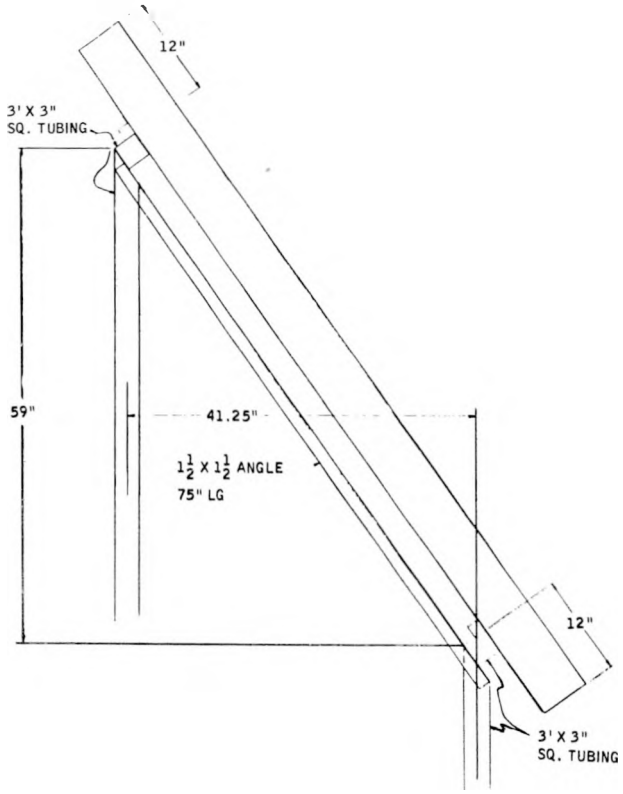


Fig. 6 — End View, Collector Support



Fig. 7 — Solar Collector Support Structure

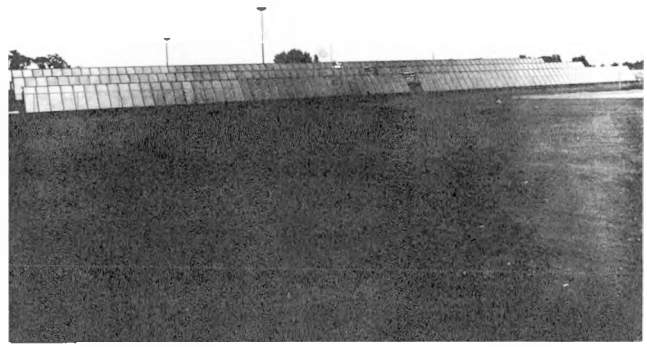


Fig. 8 — Solar Collector Field

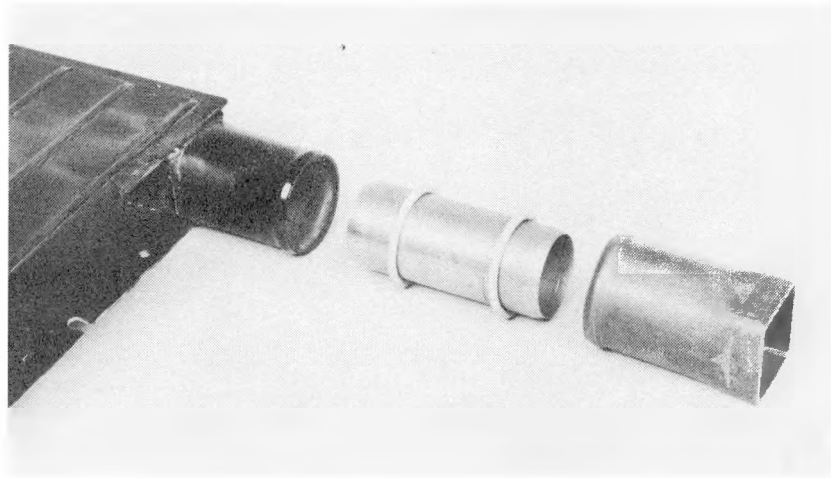


Fig. 9 — Header Connector Fix

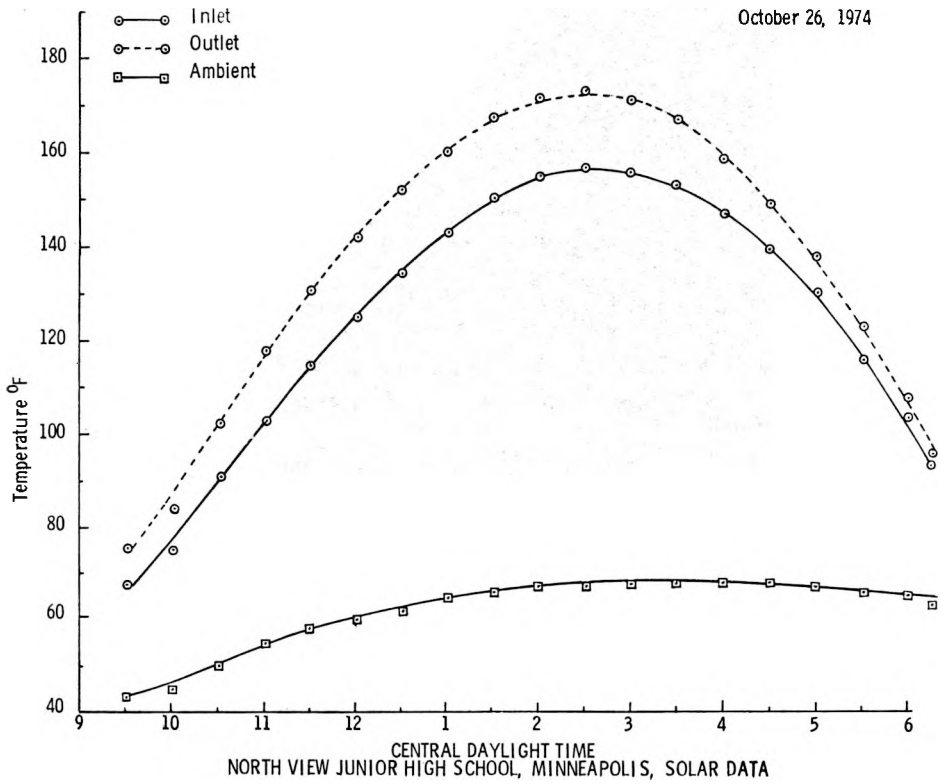


Fig. 10 — Collector Inlet, Outlet and Ambient Temperature

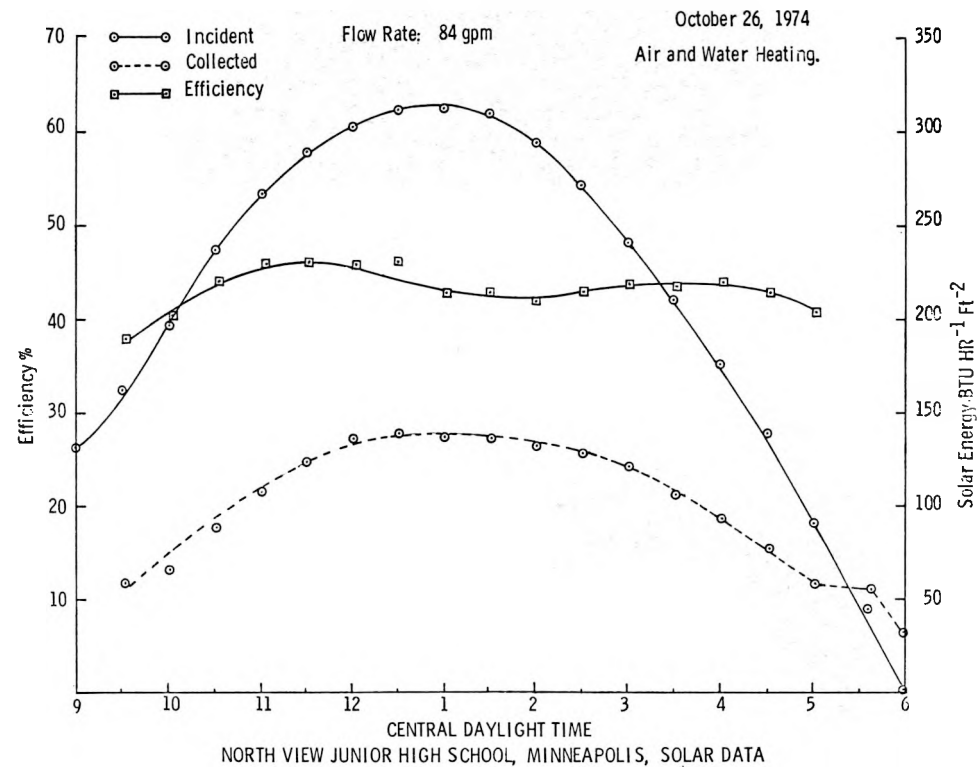


Fig. 11 — Incident and Collected Energy and Efficiency

DISCUSSION

Question (David Aronson, David Aronson Associates): Can you justify use of solar heat for heating ambient air, when much of this could be obtained from an exhaust/fresh air heat exchange device?

Answer (Glen L. Merrill, Honeywell Systems & Research): The area being heated (pool area) requires from 50 percent to 100 percent outside air, which is not exhausted conveniently for such devices. The area represents a very good match for the solar collectors when preheating incoming air.

Question (Stephen J. Winter, Guam Energy Office): Are the Honeywell collectors commercially available, and what are their costs?

Answer: They are not commercially available.

SOLAR COLLECTOR DESIGN AND PERFORMANCE EXPERIENCE THE GROVER CLEVELAND SCHOOL, BOSTON, MASSACHUSETTS

Don L. Kirkpatrick
Energy Engineering, Space Division
General Electric Company
King of Prussia, Pennsylvania

This paper describes major design features of the solar collectors installed by GE for the National Science Foundation on the Grover Cleveland Middle School, Boston, Massachusetts, in February 1974. Preliminary performance data and some aspects of collector operating experience are also briefly presented.

The solar collector array is comprised of 144 GE P3 4 x 8 ft. prototype collector modules (Figure 1). The basic P3 collector design concept is the result of a development program conducted by GE in 1973 in which particular emphasis was placed on the creation of a simple design from the standpoint of minimum parts, cost effective materials utilization and minimum fabrication labor which would serve as a prototype for low cost/high volume production. The resulting design is believed to combine inherent reliability, durability, and performance equalling or surpassing other known flat plate collectors having nonselective absorber surfaces.

The arrangement and interrelationship of the collector components is shown in Figure 2. The absorber is Type 1100 aluminum alloy, which integral fluid passages formed using the OLIN RollBond process. The resulting panel has high thermal efficiency, is light in weight and low in both material and production cost. Two 23 x 94 inch panels are mechanically and thermally bonded together to produce an absorber plate of the desired size. (Manufacturing facilities at OLIN are limited to 36 inch width for aluminum RollBond production; it was therefore decided to construct the absorber from two identical half width panels mounted in mirror-image orientation). Each panel has its own fluid inlet and outlet.

The absorber plate is coated with the 3M 301-C10 Black Velvet paint, baked at $350^{\circ}F$. Measured properties of this coating, as used in this application, are: solar absorptivity, $\alpha = 0.975$, and infrared emissivity, $\epsilon = 0.907$. 3M's published weathering data for direct outdoor exposure indicates a three-year minimum life for this product, and a maximum continuous service temperature of $300^{\circ}F$. The long-term effects of exposure in the collector environment - low relative humidity air at elevated substrate temperatures, in the absence of UV - must be determined; it is expected that a significantly longer life will be realized in this application since the paint is protected by collector covers and operates at temperatures significantly below $300^{\circ}F$.

In the P3 collector the absorber and its molded polyurethane insulation are contained within a frame pan of weather-resistant 0.04 inch Type 5005 aluminum sheet. Combining the absorber plate, foam insulation and lightweight frame pan into a single molded assembly provides a number of unique performance enhancing and cost saving advantages. The absorber and frame pan serve as the skins of a rigid, lightweight (3 lb ft^{-2}) structural "sandwich" panel in which the cast rigid urethane foam provides

the insulation, core, and bonding agent. The absorber and frame pan define the mold cavity into which the urethane is case and subsequently protect it against moisture infiltration, preserving its high insulating value. (The thermal conductivity of this 2 inch insulating core is $\simeq 0.07$ BTU h^{-1} ft^{-2} F^{o-1}). The multifunctional use of materials, and the simplicity of the foam casting process, which can be almost fully automated, offers the potential for economical production by minimizing material and labor costs, as well as efficiently utilizing materials. The lightweight of the P3 collector (100 lb per 4 x 8 ft. module) also reduces transportation and installation costs compared to panels of more conventional design and materials.

The inner and outer windows are made of 0.08 inch LEXAN UV-inhibited polycarbonate plastic sheet. Both windows have integral thermo-formed stiffening ribs which serve to accurately control the spacing of the windows in order to minimize conductive and convective heat losses. The point contacts where the ribs cross also minimize outward thermal losses through the low thermal conductivity plastic. The continuous lip which overlaps the frame pan of the collector is also integrally formed into the outer window of the collector, providing a simple but effective weather sealing mechanism in conjunction with the butyl glazing sealant strip around the entire perimeter of the window. Porous plugs are provided to vent the cavity between the absorber and the inner window, allowing for air expansion and the expulsion of water vapor. These plugs are protected by the window lips from direct weather exposure.

LEXAN 0.08 sheet weighs 0.5 lb ft^{-2}, versus approximately 1.7 lb ft^{-2} for 0.125 tempered glass, providing a weight saving of at least 77 lbs. for a double glazed 4 x 8 ft. collector using polycarbonate windows. This weight saving is particularly important in terms of its effect on handling, shipping, and installation costs, as well as on new building structural costs, or, in the case of existing structures, on allowable load limits.

Glass, even if heat strengthened or tempered is also more susceptible to breakage than the polycarbonate material. It is interesting to note that among all the collectors built for the four recently completed NSF school solar heating systems, the three collectors arrays using glass windows have each experienced breakage due to handling, thermally induced stresses, missile impact or combinations of these causes. Only the LEXAN windows have remained intact, notwithstanding their being subjected to bombardment with a basefall, and rocks up to the size of railroad ballast.

Analytical performance predictions for the P3 solar collector and for a similar collector using 0.125 inch low iron glass covers were prepared; the results are presented in Figure 3. A conservative value of integrated solar transmittance ($\tau = 0.83$) was used for the LEXAN while $\tau = 0.90$ was used for the glass. The predicted efficiencies for the LEXAN covered collector model were approximately 5-6 percentage points lower than for the similar case with low-iron glass covers. Subsequent performance results from actual tests of the P3 collectors both in the Boston installation and at the GE Valley Forge test facility are given in Figure 4. The solid line curves are analytical predictions of collector performance with insolation values of 200 and 300 BTU hr^{-1} ft^{-2}, at zero incidence, $70^{o}F$ ambient air temperature, collector tilt of 50^{o} from the horizontal and wind speed of 10 mph. Total insolation was assumed to be composed of 90% direct and 10% diffuse radiation. These data indicate that

collector efficiency was in all cases somewhat higher than predicted using the same analytical model as above. Testing of these collectors is continuing at both locations; this work, together with additional materials test data, is expected to provide the information needed to rationalize the differences between observed and predicted collector performance.

Figure 5 presents P3 collector data for June 3, 1974. The large effect of clouds can be seen in the variations of solar intensity. This effect points out the need to continuously integrate the solar insolation measurement during a test. Thermal capacitance effects can be noted where collector instantaneous efficiency increases during periods where the insolation has been reduced by passing clouds. Temperatures of the absorber plate, cover windows, and the rear surface of the collector frame pan for a typical collector in the Boston School installation are shown in Figure 6. All sensors used were thermocouples. The three upper curves represent absorber plate temperatures. The window temperature sensors were each mounted beneath the inner surfaces of the respective covers; of consequence the temperatures observed were influenced by the adjacent air temperature as well as the windows, which may account for their being somewhat higher than would normally be expected.

A great deal of valuable experience has been gained in the construction and operation of this system. Important "lessons learned" include the following:

1. Collectors should be designed to withstand prolonged solar exposure without coolant flow. Although it was originally planned to limit the P3 absorber temperature to 200°F under all circumstances, this did not prove practical. During collector installation and subsequent servicing several unforeseen or unavoidable circumstances occurred in which fluid could not be circulated to some or all of the collectors, resulting in absorber temperatures as high as 275-300°F. In some cases, too, it proved desirable or necessary to operate the system at fluid temperatures as high as 240°F. Both the operating and non-operating elevated temperature exposures caused irreversible thermal growth in the urethane insulation of some panels. Foam insulations stable above the maximum attainable absorber temperature have since been identified and will be used in future collector designs.

2. Galvanic corrosion should be minimized by avoiding the use of electrolytically dissimilar metals in the fluid system. While corrosion inhibitors have been successfully applied to this system, and electrical insulation of the absorbers relative to the piping has been provided, greater inherent reliability will be achieved in future systems by eliminating copper and copper alloys from the plumbing of aluminum absorber systems.

3. Use of EPDM panel-to-manifold hoses will provide greater UV and high-temperature resistance and life. The hoses selected were represented to be neoprene by the manufacturer, but were subsequently found to be buna-N. Weathering cracks in the hose jackets have been found; while these have not necessitated large scale hose replacement, they represent a potential service problem which improved materials are expected to reduce.

4. Pipe-threaded weld adapters for fluid nipple attachment to the absorbers have caused leaks due to under-tightening or over-tightening of the nipples. In the latter case, cracked welds have occurred on two panels. New methods of tube attachment to the RollBond are being developed.

In summary, notwithstanding the problems encountered with this experimental system, the collectors on the whole have consistently performed better than predicted, demonstrating the general validity of the design, and the suitability of most of the materials with which it was implemented.

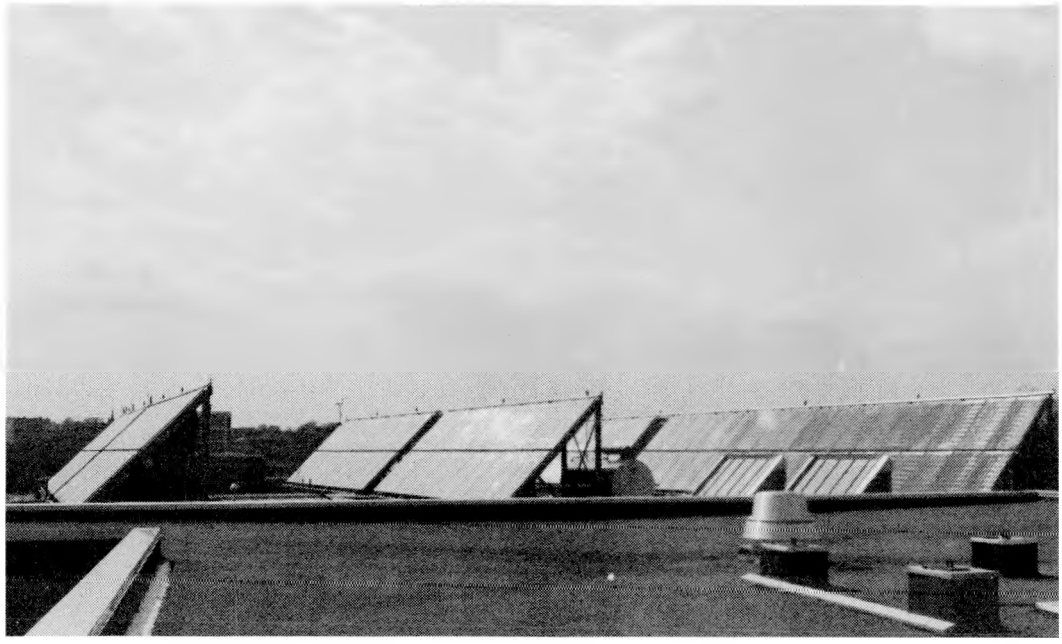


Fig. 1 — One Hundred Forty-four P3 Collectors Installed on the Grover Cleveland Middle School in Boston, Mass.

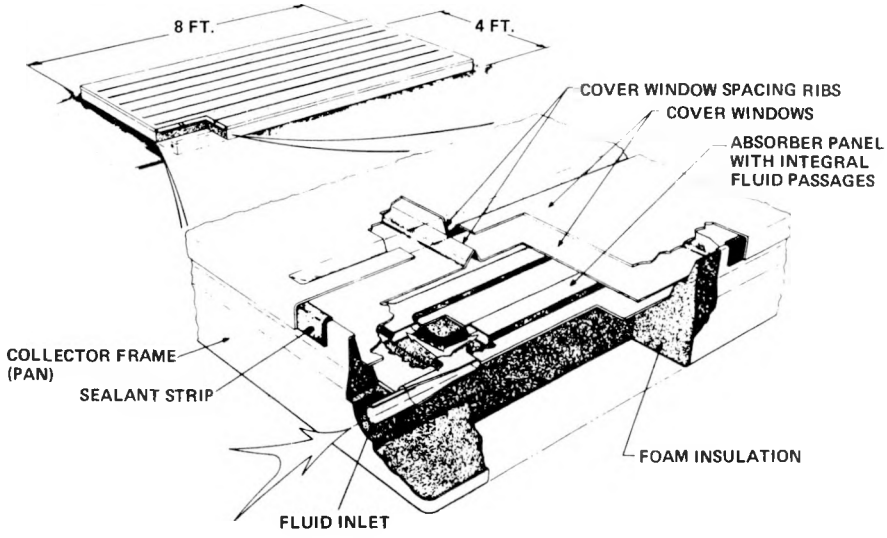


Fig. 2 — GE P3 Prototype Solar Collector Used in NSF Boston School Project

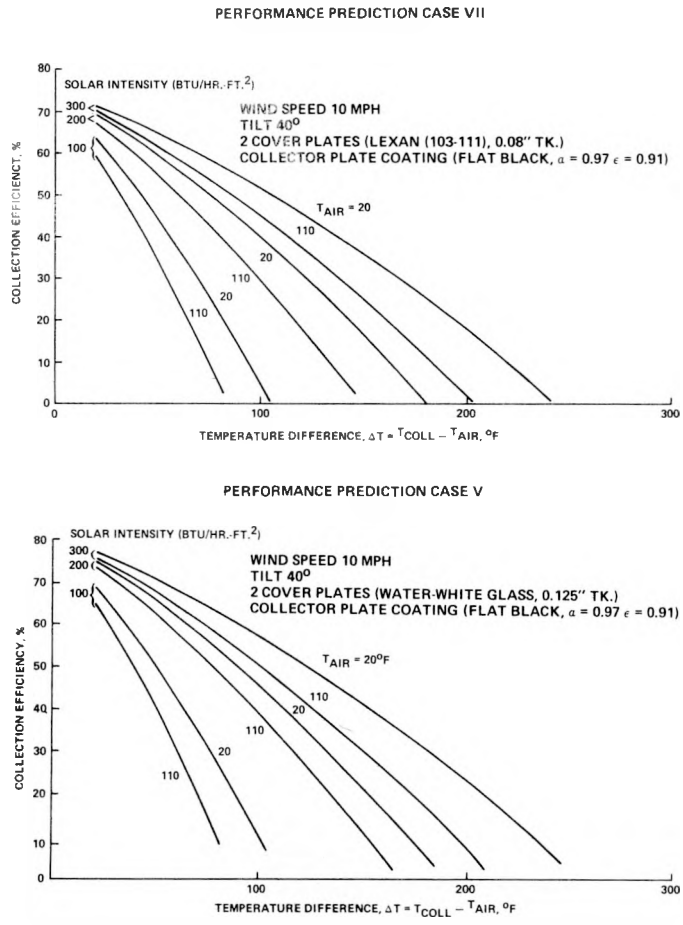


Fig. 3 – Collector Performance Predictions

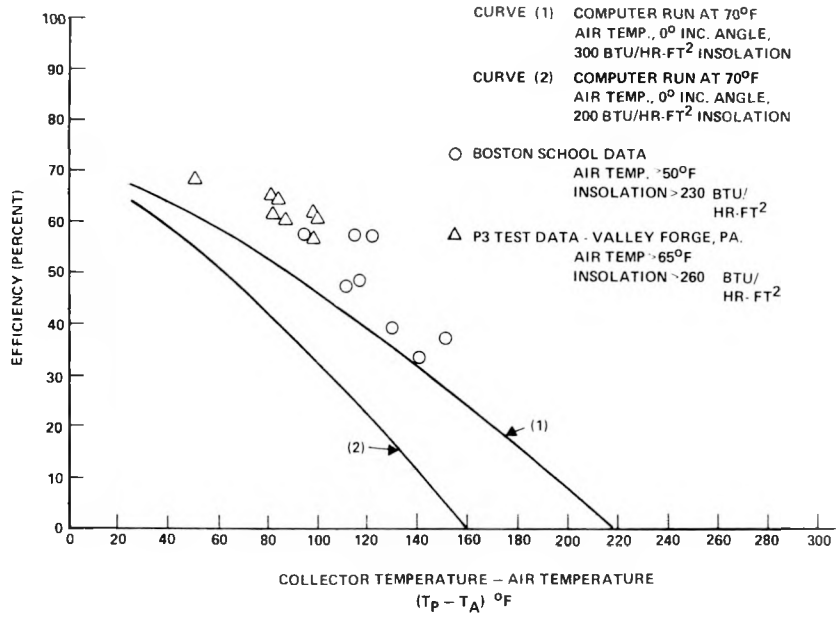


Fig. 4 – GE P3 Collector Data – Boston and Valley Forge

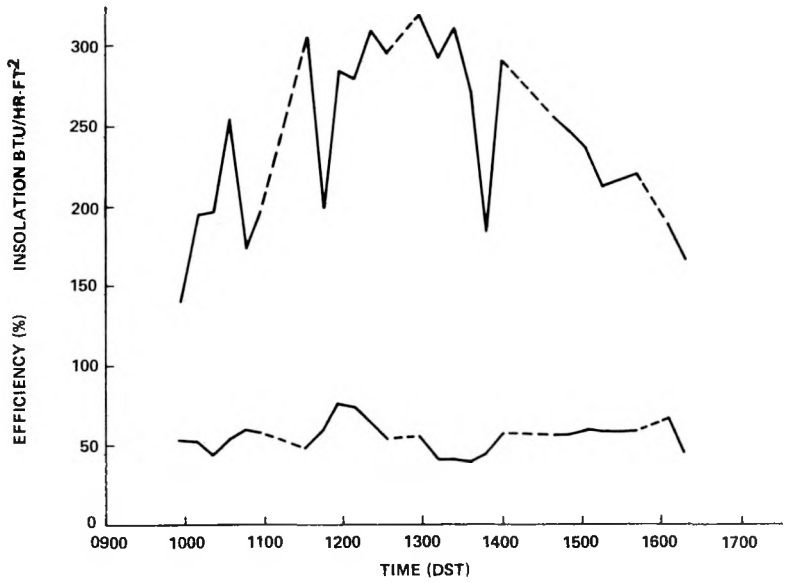


Fig. 5 – P3 (3-M Coating) Solar Collector Test Data

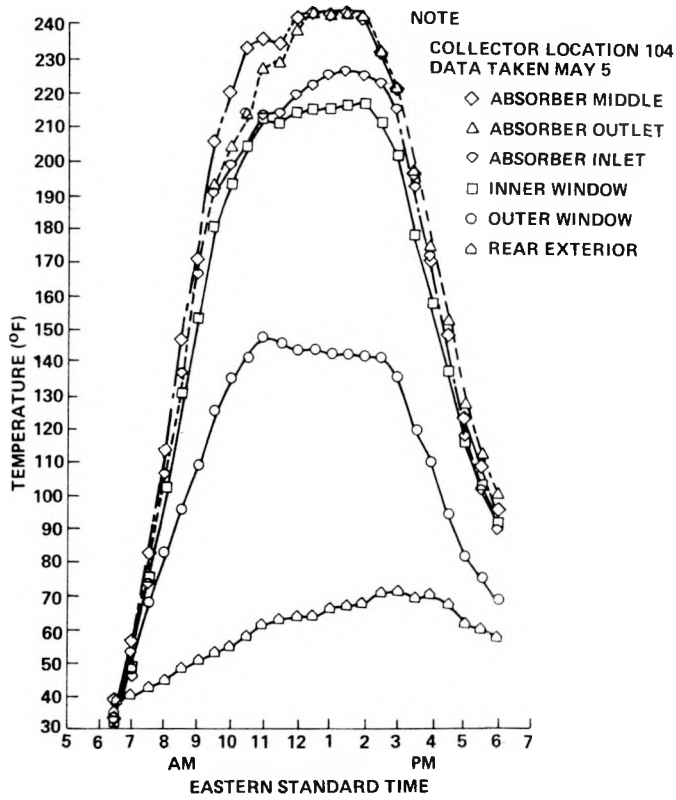


Fig. 6 – P3 Solar Collector Temperature Distribution, 5 May 1974, Collector 104, Grover Cleveland School

DISCUSSION

Question (Stanley A. Mumma, Ohio State University): What is the IR transmission of plastic as opposed to glass?

Answer (D. L. Kirkpatrick, General Electric): The plastic used in the Grover Cleveland Middle School solar collectors is 80-mil GE LEXAN® polycarbonate. Its IR transmission in terms of the radiation from a 100° C black body is about 1 percent in the 2-3-micron interval, and less than 1 percent for any 1-micron interval at longer wavelengths. We cannot give a specific answer relative to glass without knowing the composition and thickness of the glass.

Question (Paul O. McCormick, Lockheed Missiles & Space Co.): What about flutter (due to wind) characteristics of plastic coverings and effect of flutter on free convection heat loss from inner to outer cover?

Answer: Very little wind-induced flutter has been observed in the 80-mil LEXAN® (polycarbonate) covers of the collectors. Unlike solely edge-supported thin film (2-4 mil) membrane covers, these windows contain integral stiffening ribs which make 54 point contacts with the inner window. Damping occurs at these points and also around the entire perimeter, which is embedded in viscous butyl glazing compound.

The effect of the occasional flutter which does occur in the outer cover on free convection between the covers is difficult to assess. The discussion by A. E. Bergles (pp. 10-18 in *Handbook of Heat Transfer,* W. M. Rosenhow and J. P. Hartnett, editors) indicates that, while the occasional vibration of air may increase, decrease, or have no effect on heat transfer by free convection, either change is likely to be small.

Question (George B. Cain, Copper Development Association, Inc.): Will Grover Cleveland Junior High School collector panels be converted to a heat-transfer oil solution to prevent internal corrosion failure? What will be the effect on efficiency?

Answer: There is no evidence of need to change the heat-transfer fluid (local water–ethylene glycol–corrosion inhibitors and buffers) in the system; consequently, no change is currently planned. The fluid pH is monitored and controlled as required with appropriate inhibitors/buffers. An absorber was sectioned and metallographically examined after 10 months of service; no evidence of corrosion was found.

52,073

FLAT-PLATE SYSTEM OPERATION & ECONOMICS: TIMONIUM ELEMENTARY SCHOOL

Irwin R. Barr

AAI Corporation
Baltimore, Maryland

This presentation is a description of the solar collector system now successfully heating a portion of an elementary school in Timonium, Maryland, and the economics of this type of collector. This experiment was designed, built and installed in 6 weeks. It was accelerated in order to gain a full year on the acquisition of data to prove the feasibility of such a system. This project was sponsored by NSF under the RANN program. The school selected is representative of many Maryland schools. It is a one-story structure with window walls on one side of each room.

Figure 1 shows the completed system which utilizes 5,000 square feet of collector mounted on the roof. A 15,000-gallon aluminum tank is used for storage. The solar collector banks are located on the central wing and heat that wing completely.

The whole array is completely instrumented so that we can determine the temperature of individual collectors and the efficiency of each bank of collectors. Recording instruments shown in Figure 2 make the experiment a large solar energy data bank.

As seen in Figure 3, 10 banks of collectors, inclined at 45 degrees, are arranged on the central wing supported only on the wall structure with no connection to the roof. Insulated distributor lines evenly distribute the water to be heated by the 180 collectors.

The basic collector, shown in Figure 4, has a double glass layer separated by a large-cell aluminum honeycomb. A black honeycomb separates the inner glass layer from the aluminum sheet which is the absorber. The bottom layer of aluminum honeycomb and aluminum sheet have a high temperature epoxy black paint as the coating. Water passages along the bottom of the honeycomb allow gravity flow from top to bottom. The water flows through thin slots adjacent to the bottom plate in each honeycomb row and makes fine, slow-moving streams which pick up all the heat from the panel and the lower portion of the honeycomb.

Figure 5 shows a typical 4′ x 7′ module, one of the 180 used on the building.

The operation is shown graphically in Figure 6. Cold water from the bottom of the tank is pumped to the top of the solar collectors where it flows through the double-glass collectors, is heated by the sun, and is returned to the top of the tank. This cycle goes on whenever the sun is shining with sufficient energy to increase the temperature of the storage tank. The second part of the cycle is independent of the collector and consists of pumping the heated water from the top of the tank through convectors in the schoolrooms, then back to the cold water side of the tank.

Figure 7 shows a typical day's operation. The upper curve shows the available BTU in the tank for school heating. The curve also shows the temperature of that tank. At 12:00 midnight heat is going into the school. This rate is increased at about 7:00 a.m., but by 9:00 a.m. very little additional heat is required until after the children leave. By 10:00 a.m. solar heat is being added to the tank as shown on the curve of BTU's collected, and by noon when solar insolation reaches 225 BTU per square foot per hour, the input is maximum.

Fig. 8 shows a plot of efficiency versus time of day for a water outlet of approximately 160°F where the ambient temperature is 70°F. The solar insolation is also shown plotted versus time of day.

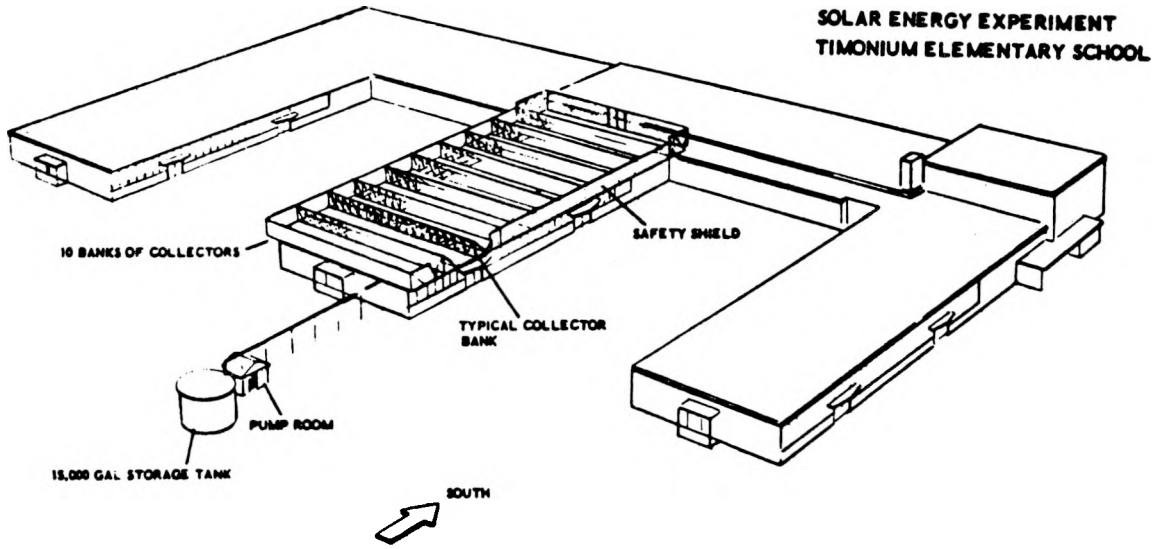
Figure 9 shows our conclusions regarding the cost effectiveness of retrofitting schools for solar heating in Maryland.

In October AAI was awarded a contract to add air-conditioning operated by solar power to the Timonium Elementary School. In order to increase the amount of energy available, AAI had proposed the addition of mirror reflectors. These reflectors would be operable only in the spring, fall and summer to increase the amount of solar energy falling on the collector and so increase the amount of energy available for air conditioning. A standard York absorption air-conditioner is used, rated to produce 50 tons using 180°F water.

An overall view of the system using the reflectors and the absorption chiller is shown in Figure 10.

A schematic of the air-conditioning system is shown in Figure 11. The cycle shows the cooler water being pumped to the solar collectors where the combination of direct and reflected sunlight heats the water to 200°F. This can then be run directly or from storage through the absorption air-conditioner generator. The chill water produced is run directly into the school. It is also planned that a system using chiller water storage in lieu of hot water storage will be employed to substantiate another part of the air-conditioning experiment.

The solar air-conditioning experiment is scheduled to begin operation in May 1975.



Data Sheet
Timonium Elementary School
Solar Heating Pilot Project

Area Center Wing (67 x 143)	**9581 sq. ft.**
Solar Panel Area	**28 sq. ft.**
Area of Solar Collector (180 panels)	**5040 sq. ft.**
Ratio of Collector Area to Floor Area	**.527**
Storage - Hot Water Volume	**15,000 gal.**
Ratio of Storage Volume to Collector Area	**2.98 gal./sq. ft.**

Fig. 1 — System Sketch and Data Sheet

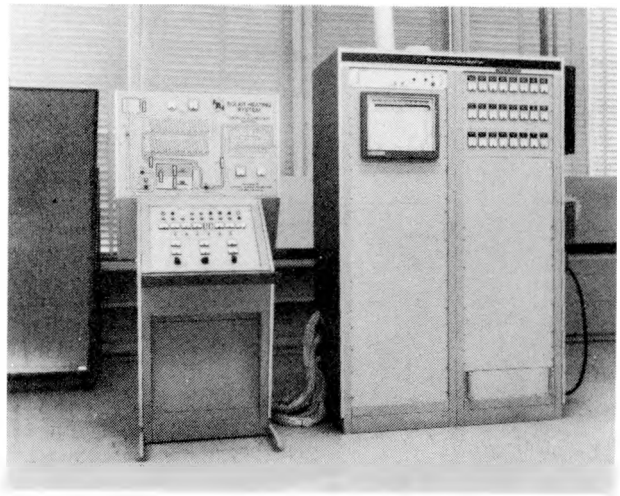


Fig. 2 – Solar Heating Control Panel and Instrument Cabinet



Fig. 3 – Array of 180 Solar Collectors

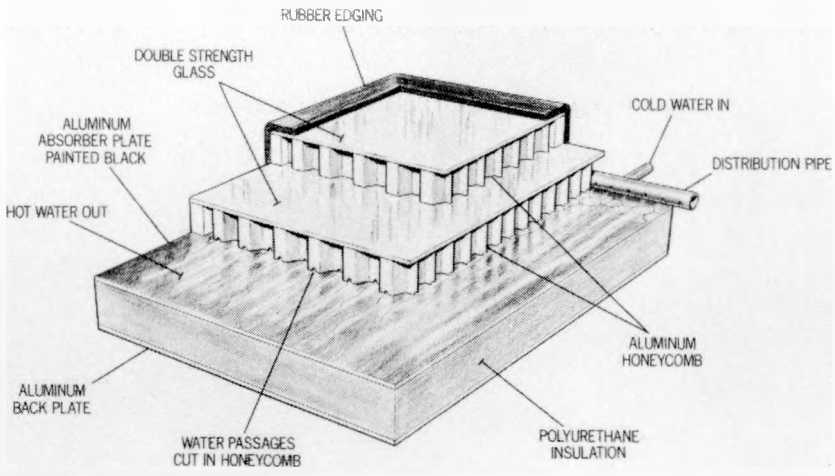


Fig. 4 – Cross Section of AAI Flat Plate Collector

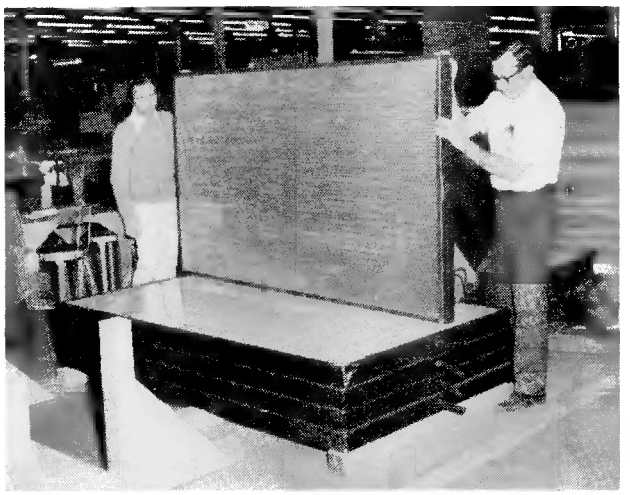


Fig. 5 — Collectors in AAI Manufacturing Area

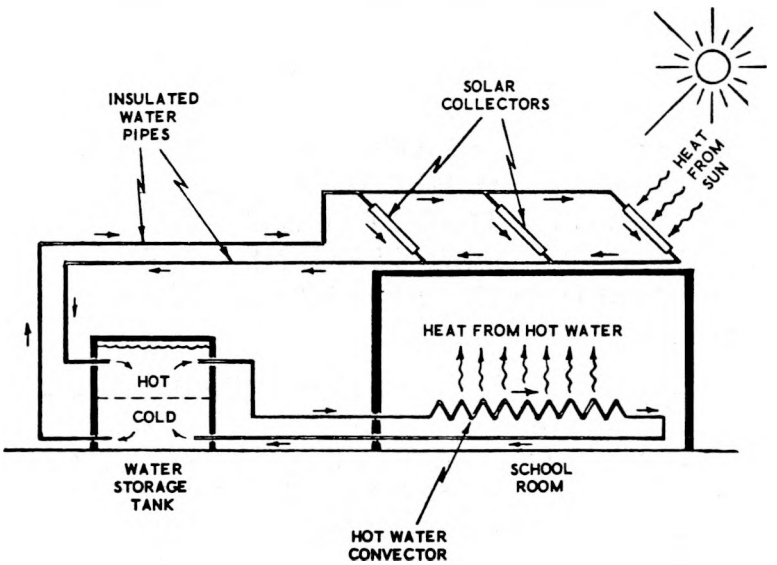


Fig. 6 — Heating System Schematic

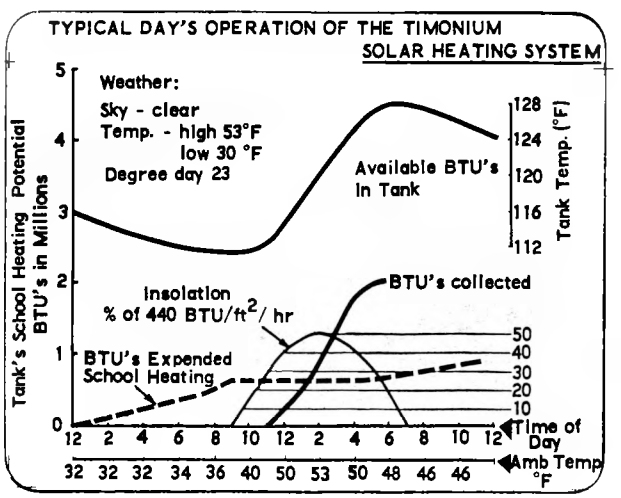
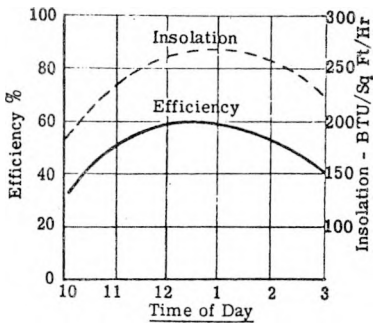


Fig. 7 — Typical Day's Operation of the Timonium Solar Heating System



A. M. Inlet Water 140°F
P. M. Inlet Water 147°F
Outlet @ 156°F Avg.
Temp. Ambient 70°F Avg.
April 29, 1974 - No wind, Clear

Fig. 8 – Collector Efficiency vs. Time of Day

CONCLUSIONS

RETROFITTING SCHOOLS FOR SOLAR HEATING IS NOT ECONOMICALLY FEASIBLE IN THE 1975-1980 TIME FRAME IN THE MARYLAND/WASHINGTON AREA WHEN COMPARED WITH PRESENT COSTS OF FOSSIL FUELS.

SOLAR HEATING FOR NEW SCHOOLS WILL BE ECONOMICALLY FEASIBLE IF THE SYSTEM COST CAN BE HELD TO $10.00 PER SQUARE FOOT (ASSUMING THE COST OF FUEL WILL NEARLY DOUBLE IN 10 YEARS).

Fig. 9 – Conclusions of Study

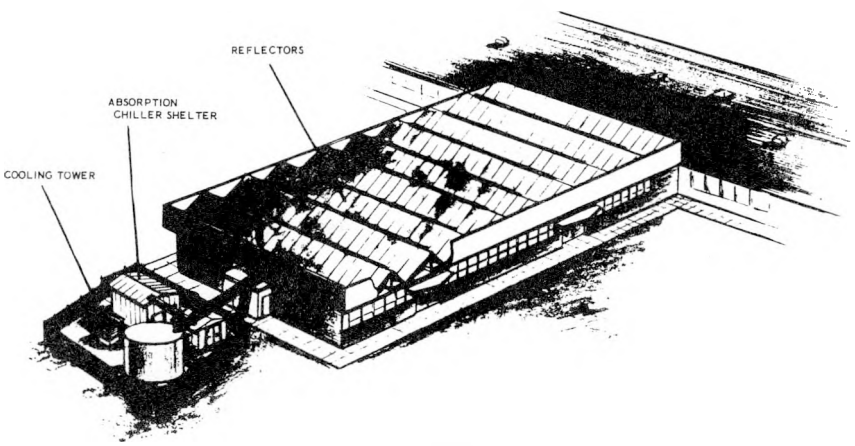


Fig. 10 – Artist's Concept of Air Conditioning Installation at Timonium Elementary School

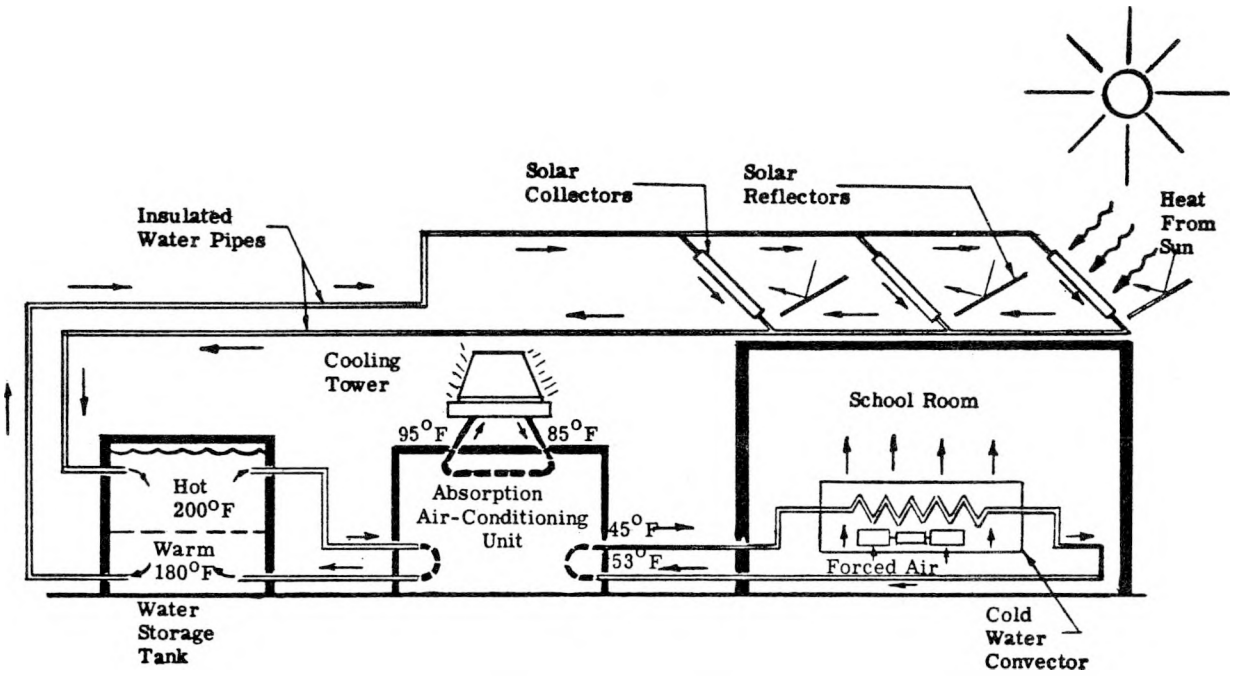


Fig. 11 – Schematic of Air Conditioning System Using Absorption Unit

DISCUSSION

Question (Frank DeWinter, Atlas Corporation): Could you comment on the effectiveness of corrosion inhibitors in the aluminum collectors?

Answer (Erwin R. Barr, AAI Corporation): Deionized water was the only water treatment used for the Timonium School experiment. In 1 year of operation, no corrosion of the aluminum honeycomb or aluminum absorber plate is evident.

Question (Richard Brecher, Energy Utilization Systems): Is the collector at Timonium School a trickling-water design with no enclosed water channels? If so, describe the means for assuring uniform unit-area flow rates.

Answer: A horizontal tube with evenly spaced 1/16-in.-diameter holes is mounted at the top of the collector. Water is fed into this tube and is distributed over the collector. The trickling water is kept in vertical channels by the arrangement of honeycomb cells that have notches cut to allow the water to flow through.

Question (Mehmet K. Selcuk, Jet Propulsion Laboratory): Would you please quantify the collector efficiency at temperatures around 160°-180° F. Is it of the order of 60 percent—which is not very likely? What happens to a collector that runs dry then is flooded with water; air bubble and vapor removal; water vapor leakage?

Answer: At water temperatures of 140°-150° F, efficiencies of 30 to 60 percent have been observed. During the summer, under no-load condition, the entire 15,000 gal were heated to temperatures averaging 194° F. Data are now being collected on efficiencies at temperatures above 150° F.

In our 1 year of operation, we have had no problems with thermal shock caused by water running over a very hot collector. Air bubbles have not occurred in any significant amount. Some condensation under the bottom glass has occurred, but disappears when the collector is in operation.

Question (George O. G. Lof, Colorado State University): Forty percent efficiency is totally unrealistic for monthly performance in December and January. Why do you not use the widely available analytical procedures to obtain a valid forecast?

Answer: You are absolutely right. The Vu-graphs we had were from our original proposal, which, in the 6 weeks we had to do it, included a very preliminary estimate of what efficiency we would get. We have used the samples in ASHRAE for all our calculations after that first 6 weeks.

Comment (Mr. Lof): Heat and mass transfer principles make it impossible for the performance of your honeycomb wet collector to equal the performance of a conventional double-glazed dry collector. Your comparison experiment should be examined for error.

Response: We did not compare it with a dry collector. We were comparing it with two glass covers and a selective coating similar to the Roll-Bond® collector, and two glass covers with black, both of which we made. Our collector is not as good as one with two glass covers and a selective coating, but is better than one with two glass covers and flat black coating at 0.9 absorptivity and 0.9 emissivity. So we are somewhere in between. The losses that we get through the conductive honeycomb have been made up by using a small gap of insulated glass microballoons 3 microns in diameter and hollow. Aluminum has a conductivity of 120; the glass microballoon insulation gap has conductivity of about 0.4. The resultant conductivity across the aluminum is dropped to that across the gap and we have outward loss coefficients established by both tests in running hot water through it and also in operation with solar energy coming in. The black honeycomb on the bottom is conductively connected to the absorber plate and is insulated from the glass in the one above it. The simple operation of running hot water through with ambient temperatures will give you the outward loss coefficients of any collector system.

EXPERIMENTAL EVALUATION OF FLAT-PLATE COLLECTOR CONFIGURATIONS

James W. Ramsey
Honeywell Inc.
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Presentation Summary

Honeywell, under the sponsorship of NASA-Lewis Research Center, is conducting a study to analyze, design, fabricate and test flat plate solar collectors for the heating and cooling of buildings. The test phase of the contract is an integrated program consisting of both outdoor testing using natural sunlight and indoor testing using a solar simulator. The results presented herein were obtained using the indoor facility. The solar simulator used is similar to the one constructed at NASA-Lewis Research Center (NASA TM X-17427 and NASA TM X-3059). The radiation source consists of tungsten-halogen lamps arranged in an array with fresnel lenses placed at the focal distance to collimate the radiation. The lamps have a dichroic coating which reduces the infrared output and therefore permits a close spectral match to solar radiation.

A broad set of collector designs are being investigated. The collectors whose performance is described in this presentation were all built identically with respect to their mechanical housing, their mounting brackets for the absorber plate, the edge and back insulation and the spacing and mounting of cover plates. Differences exist in the collectors only in regard to the type of absorber plate surface coating and the number and type of cover plates.

The basic configuration of the collectors is shown in Figure 1. They have 44 x 44 inch Roll-Bond aluminum absorber panels with two inches of insulation around the edges and three inches of insulation on the back. They have one or two cover plates and are assembled in a light gage steel box.

Figures 2 through 6 present the performance data for five of the collectors tested. The tests were performed at fluid inlet temperatures ranging from 80F to 200F and incident flux levels ranging from 150 to 320 Btu/hr-ft^2. The collector fluid was a 50/50 mixture of ethylene glycol and water. The collector fluid flow rate was 10 lbm/hr-ft^2. The test results are presented by plotting the collector efficiency, Q/Q_{INC}, as a function of the parameter $(t_{IN} - t_{AMB}/Q_{INC}$ where:

Q = heat delivered to the collector fluid, (Btu per hour per square foot of absorber area)

Q_{INC} = incident solar flux (Btu per hour per square foot of absorber area)

t_{AMB} = ambient temperature, (^{O}F)

t_{IN} = fluid inlet temperature, (^{O}F)

Figure 2 presents the performance of a collector having a black absorber surface coating and two glass cover plates. The surface coating is 3M Black Velvet paint which has a solar absorptance of approximately 97 percent. The performance improvement resulting from the use of a selective absorber surface is shown in Figure 3. The selective surface was an electroplated two layer black nickel coating on a bright nickel coated absorber panel. The solar absorptance of the surface was 0.94 and the emittance at 200^{O}F was 0.08.

Figure 4 presents the performance of a collector that has a black absorber plate and a glass outer cover and Tedlar inner cover. It is seen that little or no effect was observed between this unit and one using two glass covers. The glass outer cover/Tedlar inner cover combination was also evaluated when used with a selectively coated absorber panel. The results are given in Figure 5. Comparing Figure 5 with Figure 3 indicates that the

substitution of Tedlar for glass as the inner cover had little effect on performance. The use of a single cover plate and a selectively coated absorber plate was also investigated. The test results for this configuration are presented in Figure 6.

Comparisons of the performances of the collectors tested are shown in Figures 7 and 8. Charts showing the efficiencies of the various collectors operating at three incident flux levels are presented. The collector configurations are listed along the bottom of each chart. In specifying the collectors the abbreviations used are; SEL = selective absorber, BL = black absorber, GL = glass, TD = Tedlar, and LEX = Lexan. Where two cover materials are used the outer cover is listed first. Note that in addition to the collectors previously discussed, two collectors having single Lexan covers are included in Figures 7 and 8. The efficiency of the collector is indicated by the open circles on the charts and the dashed lines are included only to assist in making the comparisons between collectors. Examination of Figure 7 reveals that when operating with the inlet fluid temperature of 120F and only $50^{o}F$ above the ambient, relatively small differences in efficiency exist for the collectors tested. However, for inlet temperatures of $200^{o}F$ ($130^{o}F$ above the ambient), large differences in efficiency exist. For this condition, which is typical of that required for use of a collector with an absorption air conditioner, the selectively coated collectors are distinctly better.

In addition to the results presented herein, performance has been measured for a number of other collector configurations using the solar simulator. In addition, outdoor tests have been conducted on two collectors, black absorber -- two glass covers and selective absorber -- two glass covers. All of the results will be presented in the final report for NASA-Lewis Research Center.

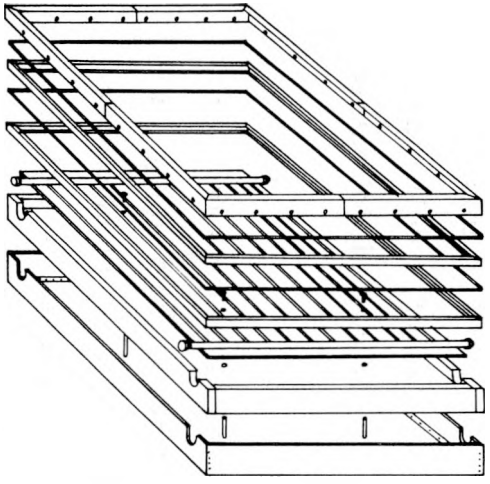


Fig. 1 — Flat Plate Solar Collector Assembly

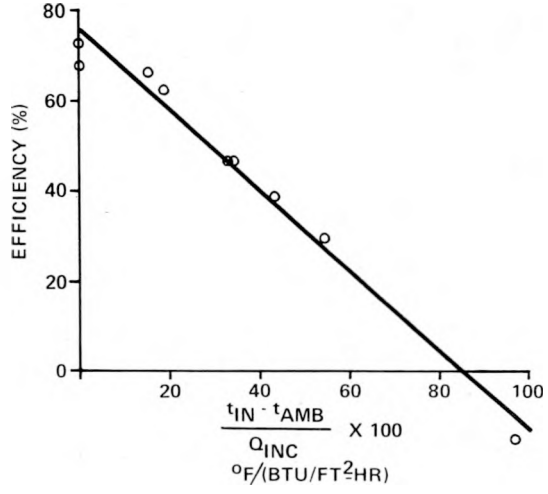


Fig. 2 — Black Absorber—Two Glass Covers

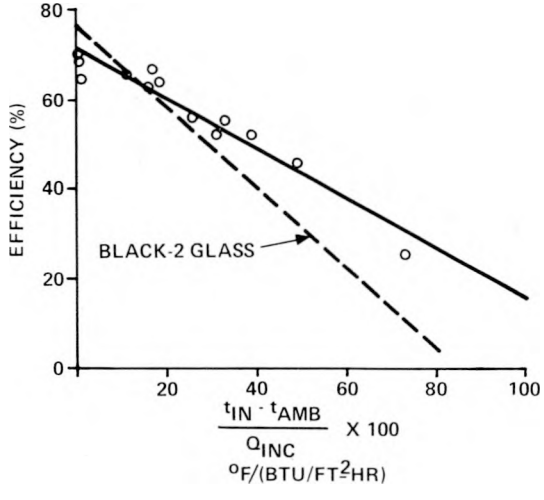


Fig. 3 — Selective Absorber—Two Glass Covers

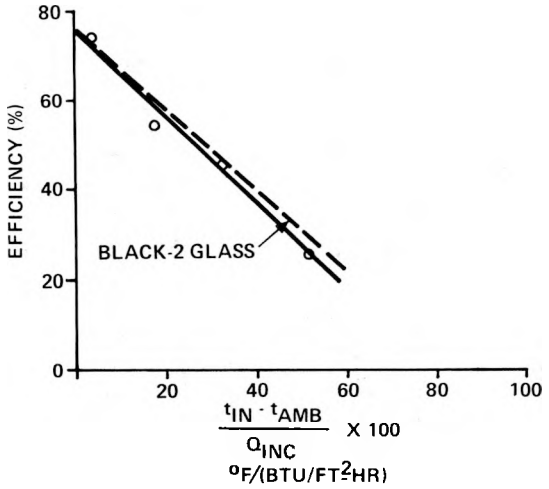


Fig. 4 — Black Absorber—Glass Outer Cover and Tedlar Inner Cover

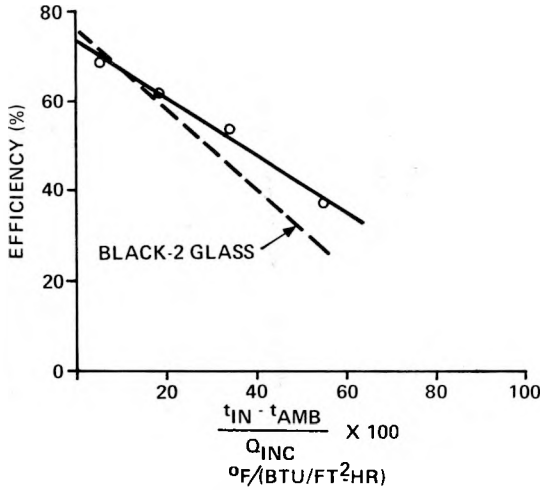


Fig. 5 — Selective Absorber—Glass Outer Cover and Tedlar Inner Cover

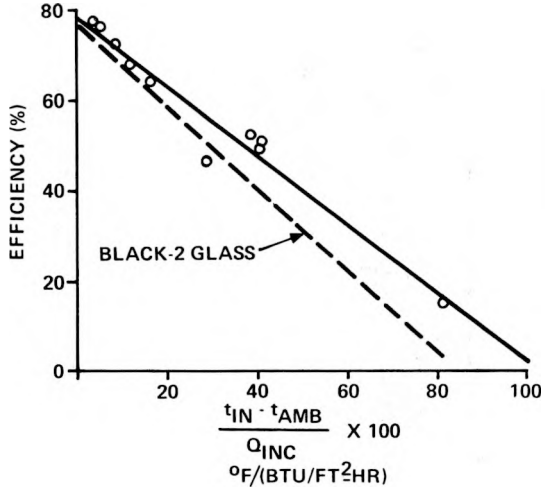


Fig. 6 — Selective Absorber—One Glass Cover

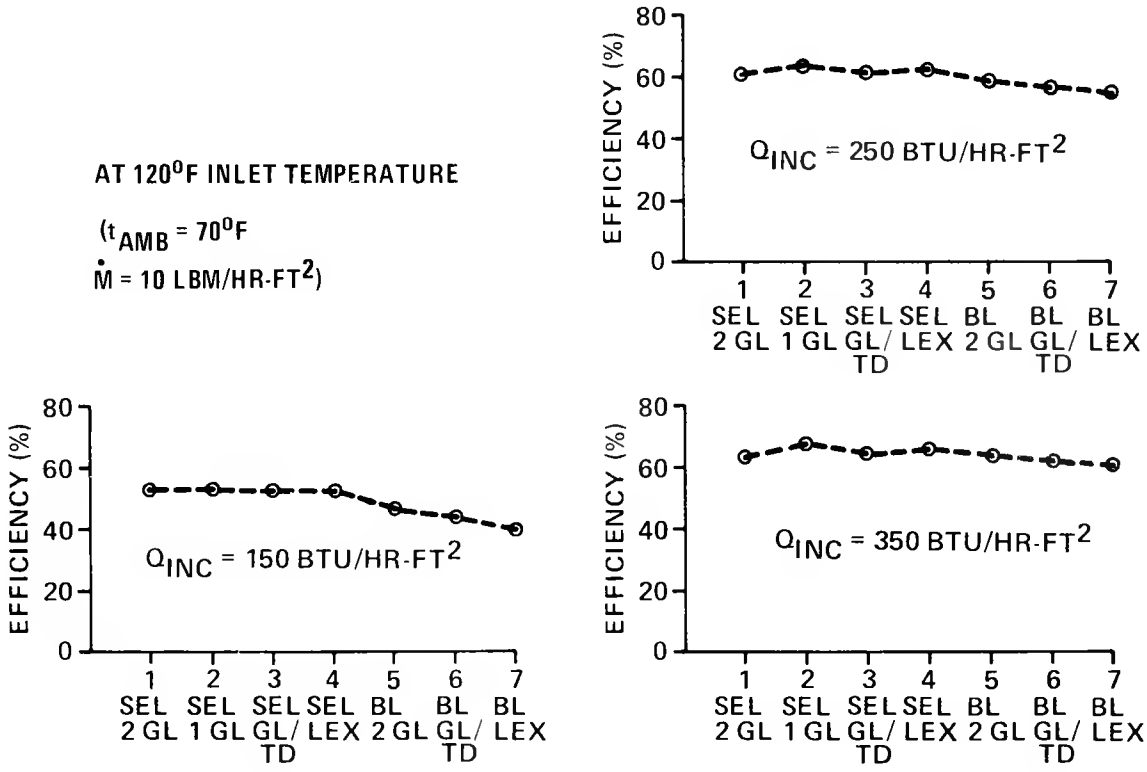


Fig. 7 – Comparison of Different Collector Designs

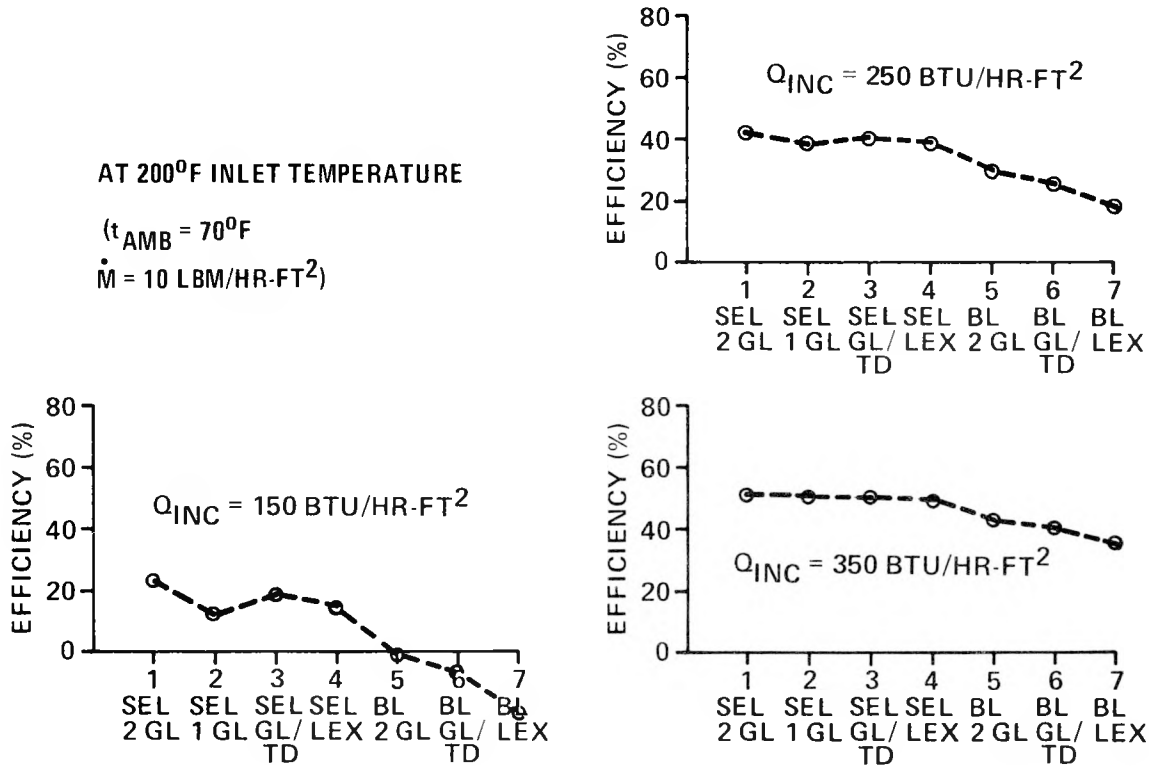


Fig. 8 – Comparison of Different Collector Designs

DISCUSSION

Question (Clarence W. Clarkson, ASG Industries): In your testing program, have you tested or do you plan to test water-white crystal-glass glazing performance as compared with the performance of float-glass glazing and sheet glass (low iron oxide content)?

Answer (James W. Ramsey, Honeywell, Inc.): Most of the glass cover collectors that we have built and tested used Fourco Clearlite, which is a low-iron, high-transmission product. We have not tested collectors with ASG water-white crystal glass.

Question (Richard M. Winegarner, Optical Coating Laboratory): You mentioned an $\alpha_s = 0.96$ and $\epsilon_{IR} = 0.06$ for black nickel. Are these laboratory sample measurements or actual values to be expected over large areas? Do your efficiency measurements verify these α/ϵ values?

Answer: The optical properties quoted ($\alpha_s = 0.94$, $\epsilon_{IR} = 0.06$) are actual values that have been achieved on large areas (4 ft x 4 ft). The selectively coated collector whose performance was described in the presentation has $\alpha_s = 0.94$ and $\epsilon_{IR} = 0.08$. It was shown to have significantly better performance than a similar design, but with a flat black absorber surface.

The Colorado State University
Solar Heated and Cooled House*

The NSF/RANN Solar Collector Workshop Presentation

DAN S. WARD
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Design Considerations

In the development of the solar collector for the Colorado State University Solar House I, several design criteria were adhered to. These include:

1) The use of a flat plate collector, compatible with an absorption cooling unit,

2) The utilization of "off-the-shelf", readily available components,

3) The collector acting as a roof replacement,

4) The potential for an economical collector, and

5) Aesthetic considerations.

The resulting design is shown in Figure 1. It is composed of aluminum structural supports, two sheets of B-quality double strength (1/8") window glass, an aluminum absorber plate with internal tubes ("Roll-Bond"®), and insulation beneath. The cover glasses are attached to the aluminum structure by a butyl tape and an aluminum cap strip. Approximately one-third of the glass covers have undergone an anti-reflection treatment (RCA "Magicote" process), courtesy of Honeywell, Inc. The aluminum panel has a tube pattern of parallel flow in multiple straight tubes between internal sloping manifolds. A flat-black "Nextel"® acrylic coating was baked on the aluminum surface at a temperature of 200°C (400°F). The insulation consists of 2.54 cm of unbonded glass fiber mat on a 3.81 cm "Fesco-Foam"® composite insulation. The overall insulating factor was computed to be, R = 10.7 $°Cm^2/w$. A subroof was provided at the request of the funding agency, to allow for subsequent modification and replacement of the solar collector on the experimental house.

The flat plate collector design (vice a solar concentrator) was predicated on the basis of simplicity, ready availability of components, roof replacement and integration into the building design, and aesthetic considerations. Additionally it was considered important to provide an overall building design which could be considered typical of present building techniques.

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* Research supported in part by a grant from the National Science Foundation/RANN.

A Lithium Bromide absorption unit was chosen because of its ready availability in a 3-ton capacity and the prior experience of converting this unit to utilize hot water instead of gas. Originally 86.7°C (188°F) was considered to be the lower temperature limit of heat input to the generator of the Lithium Bromide absorption cooling unit. In order to achieve this temperature a liquid (water and ethylene glycol mixture) was used as the heat transfer agent and for thermal storage. Thus a "wet" collector was used as the basis for the design.

The Roll-Bond"® absorber plate was utilized primarily for reasons of availability and simplicity. Aluminum was used as the absorber plate material (vice e.g. copper) because of economic considerations. Using presently available machinery a copper Roll-Bond® plate utilizes too much copper to be reasonably economical. Steel was also considered an alternative, but was not available in the desired configurations. Low cost plastics were rejected because of their inability to withstand the temperatures of a no-flow situation (approaching 200°C). Selective surfaces on the aluminum were not used because of cost and availability. (Note: we considered only selective surfaces with regard to aluminum absorber plates.)

Glass was used for the covers because of ready availability, low cost (with respect to high quality plastics), known durability characteristics, and the considerable backlog of information on the use of glass. In effect, known liabilities were accepted in lieu of uncertain advantages.

The selection of the tube pattern was based on two concerns: Drainage and rate of flow. A provision for drainage of the solar collector during non-daylight hours was incorporated into the design as a possible method of alleviating freezing problems and eliminating heat loss from the water in the collector at night. The flow rate was designed principally to achieve an even distribution of flow. Additionally it was desired to produce an 8°C maximum temperature rise in the heat transfer fluid as it passed through the collector.

Collector Performance

Tenative performance data has been obtained on the solar collector. It should be emphasized, however, that this data was taken from an operating collector and that under these conditions, a stable, steady-state condition is particularly difficult to obtain.

Figure 2 is a plot of collector efficiency (useful heat delivered to storage/incident solar energy) versus the incident solar radiation on a 45° tilted surface. Figure 3 plots collection efficiency against $\Delta T/Q$, where ΔT equals the difference between the temperature of the collector outlet, and the ambient air temperature. Q is the incident solar energy on a 45° tilted surface.

In each case the upper curve shows the results of several days data, and indicates a collector efficiency of 40-55% under typical solar conditions. The lower curve shows the effect on collector efficiency by a substantial

SSE wind, blowing directly onto the collector. In this case the shape of the curve is primarily a function of conduction and convection losses, and is therefore, approximately a linear function of ΔT. The slight concavity of the curve is due to the variation of collector efficiency with Q. The upper curves show a stronger dependence on Q, and in Figure 3, we see that in addition to the heat losses proportional to ΔT (conduction and convection) we also have a substantial T^4 (radiation) contribution.

An important aspect of these curves is the indication that the testing of solar collector efficiencies must be done in the real world. Testing done indoors, eliminates the variations on conduction and convection losses (due to winds, etc.) and since the collector can effectively see only the artificial "solar source", eliminates the radiative heat loss effects (a function of T^4). Neat, straight lines on collector efficiency versus $\Delta T/Q$ curves provide little useful information.

Figure 4 shows a plot of the temperatures of the middle and edge of a lower glass cover, as a function of the time of day. The important point here is the fact that the thermal stresses within a transparent cover can be quite substantial and dynamic. This should serve to indicate that plastic covers from the viewpoint of durability should be critically evaluated.

Economics

In obtaining the cost of the collector, several factors were involved:

1) The unit was a custom design of comparatively small size.

2) The collector was built up on the roof, vice a modular construction. This was necessary because of the presence of the subroof.

3) University shop personnel, normally accustomed to new and unique work assignments, did most of the assembly and installation.

4) In evaluating the necessary man hours for repetitive tasks, the time requirement for the last unit was used so that learning time would not be included.

With these factors in mind, the solar collector costs are presented in Table I.

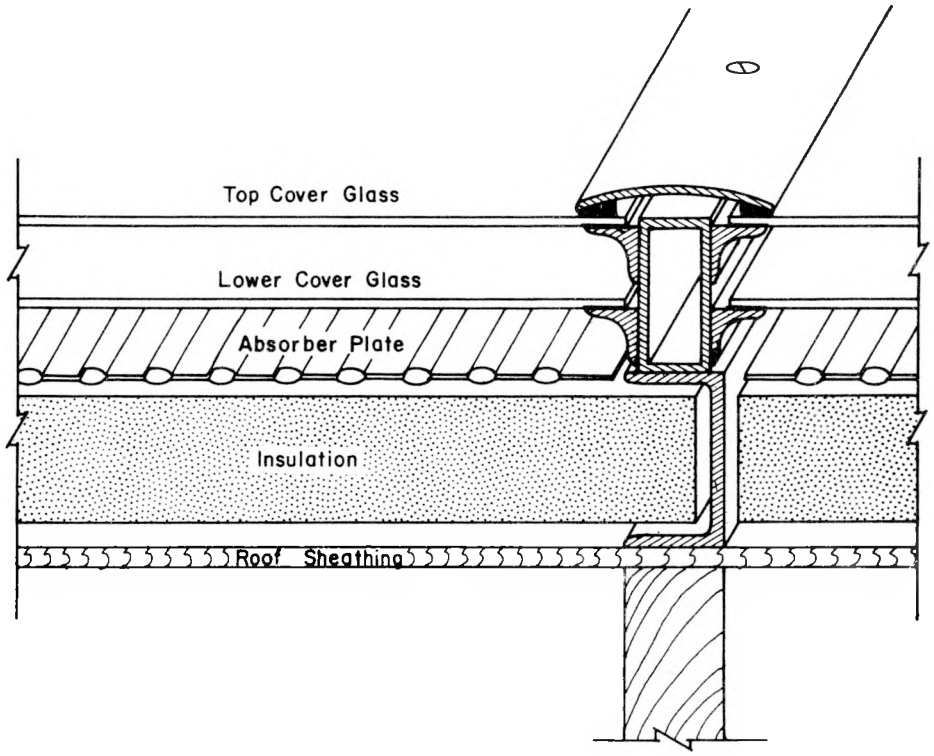


Fig. 1 — CSU House Collector Configuration

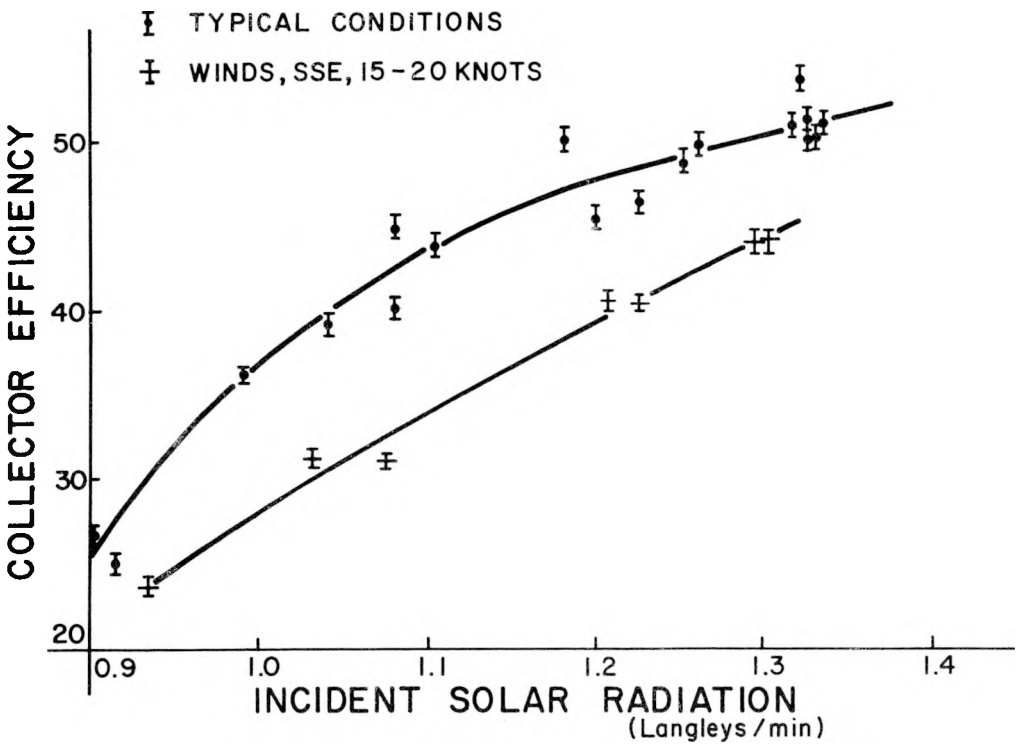


Fig. 2 — Collector Efficiency vs. Incident Radiation on a 45° Tilted Surface

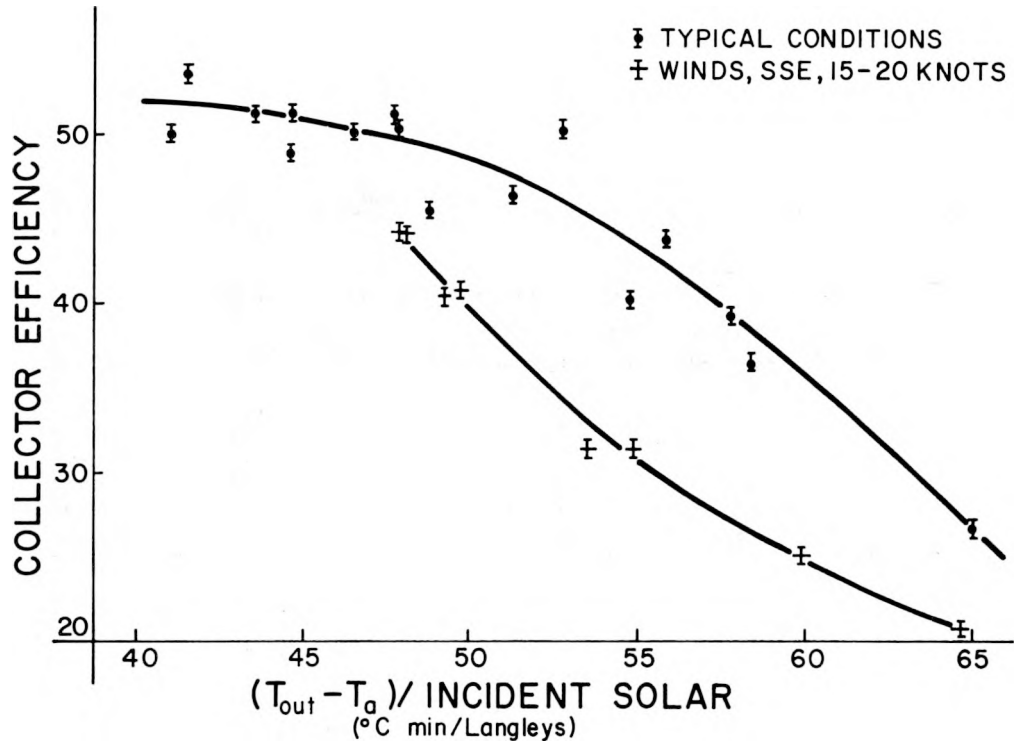


Fig. 3 – Collector Efficiency vs. Temperature Difference Between Outlet Fluid and Ambient

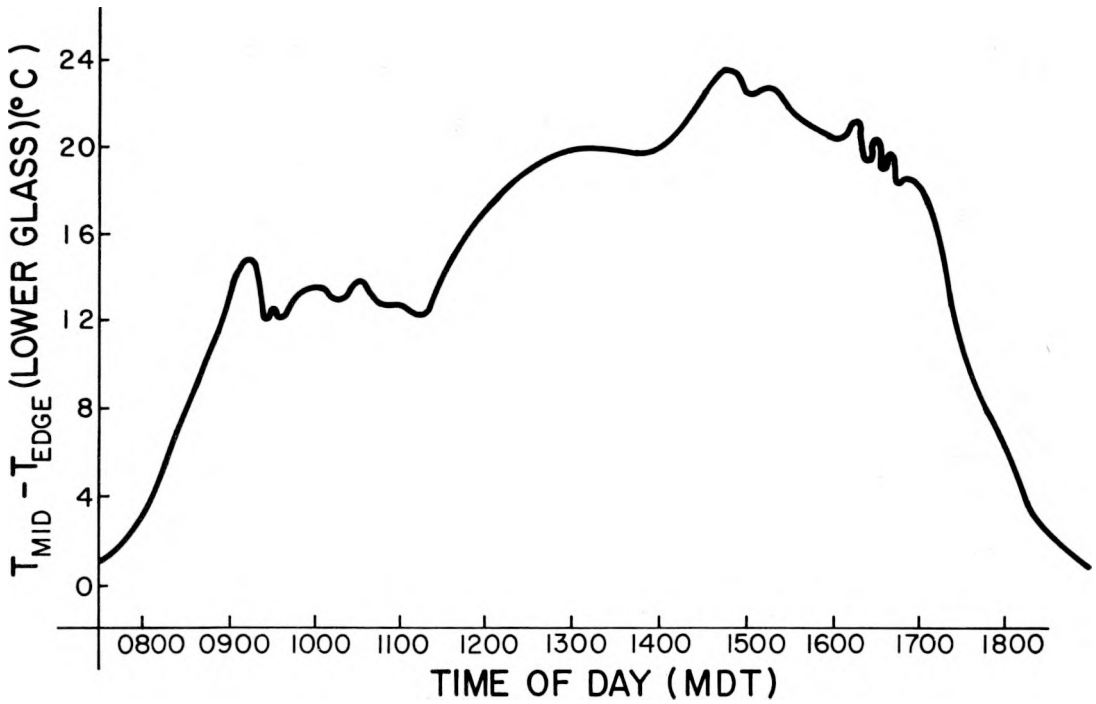


Fig. 4 – Temperature Difference Between Middle and Edge of Inner Glass Cover vs. Time of Day

Table 1

Solar Collector Costs +

Material

Item			Quantity	Total Cost	Cost/Ft^2
1/8" double strength, window (DSB) glass	[34" X 66"] (15' Rolls)	*	100 sheets	$ 526.00	$ 0.33
3/8" Butyl tape			142 rolls	312.40	--
4" x 1.72" Aluminum Channel (rafter)			240 feet	386.40	--
1 3/4" X 3" Aluminum Tube			240 feet	350.40	--
1" X 1" Aluminum Angles			992 feet	198.40	--
1/8" X 2" Aluminum Rectangle			304 feet	97.28	--
1" X 2" Aluminum T-Bar			364 feet	76.44	--
33" X 8' ROLL-BOND® absorber plates		**	32 sheets	612.48	0.85
Primer			3 gallons	20.25	0.02
NEXTEL black coating			5 gallons	90.00	0.12
Insulation B-Fiber with Fesco-Foam			750 ft^2	322.50	0.43
Miscellaneous				30.00	--
[768 ft^2 collector]	Total Material Costs			$3022.55	

Labor

Item	Man-Hours	Cost***
Cleaning Absorber Plate (32 @ 1/4 hours)	8	$ 48.00
Painting Absorber Plate (32 @ 1/2 hours)	16	96.00
Baking Absorber Plates (32 @ 1/2 hours)	16	96.00
Aluminum and Glass Frame Fabrication	18	108.00
Glass Preparation	6	36.00
Installing Aluminum Beams	28	168.00
Installing Manifolds	20	120.00
Installing Insulation/Absorber Plate/Plumbing/ Glass Units for 16 Panels [3 panels/day with 3 men]	128	768.00
Crane Time (@ $10/hour)	44	440.00
Miscellaneous	34	204.00
Total Labor Costs		$2084.00

Total Collector Costs $5106.55

or

$ 6.65/ft^2

+ Includes shipping to job site

* Allows for 4% glass breakage

** Does not include design and set up charges

*** @ $6.00/hour

DISCUSSION

Question (Thomas B. Reed, MIT Lincoln Laboratory): The shape of the efficiency versus ΔT curve depends on heat loss mechanism, i.e.,

Straight line implies loss $\sim (\Delta T)^n$ $n = 1$

Concave down $\frown$ implies loss $\sim (\Delta T)^n$ $n = > 1$

Concave up $\smile$ implies loss $\sim (\Delta T)^n$ $n < 1$

How can wind give $n < 1$?

Answer (Dan S. Ward, Colorado State University): The curves shown in figure 3 were plots of efficiency versus $\Delta T/Q$, where Q is the incident solar radiation. The concave down $\frown$ shows a $(\Delta T)^n$ where $n > 1$. This is the effect of a combination of radiation losses $(\Delta T)^4$, conduction and convection losses $(\Delta T)^1$, and the effects on efficiency of Q (shown separately in figure 2). The effect of the wind was to cause the relative contribution of radiation losses $(\Delta T)^4$ to be negligible with respect to the much more significant conduction and convection losses. The deviation from a straight line $(\Delta T)^1$ (concave up $\smile$) was due to the effects of the incident solar radiation, Q.

Question (Phillip Smith, New Mexico State University): How well did your solar air-conditioning system operate during August 1974?

Answer: The cooling system in general worked quite well during August 1974. C.O.P.'s were in the range of 0.65 to 0.80. There were no maintenance difficulties encountered. A more detailed account will be in the January Progress Report.

Question (Walter B. Bienert, Dynatherm Corporation): What fluid are you using? Do you drain at night? How do you prevent freezing?

Answer: The CSU Solar House I uses a mixture of 60 percent ethylene glycol and 40 percent water. This mixture prevents freezing.

We do not normally drain at night, although we have the capability. The concern with daily draining is the effects of corrosion on the aluminum Roll-Bond®, which is exposed to air on such a regular basis.

Question (Harold R. Hay, Skytherm Processes): Would the low-dewpoint characteristics of Colorado provide adequate cooling by radiation, evaporation, and convection at night to fully cool the house without use of the solar absorption cooler? What percent of the total cooling of the building could be accomplished by full and proper use of water evaporation employed on the chiller?

Answer: Certainly evaporative cooling has a substantial potential for cooling a house in the dry climate in Colorado. Because of this, the Solar Energy Applications Laboratory has proposed to NSF to provide an evaporative cooling system for CSU Solar House III. This will provide a much better basis for discussion of the relative merits of absorption and evaporative cooling.

52,076

STRUCTURALLY INTEGRATED STEEL SOLAR COLLECTOR DEVELOPMENT*

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Presented at "Workshop on Solar Collectors
for Heating and Cooling of Buildings,
Nov. 21-23, 1974

SUMMARY

The LASL flat plate collector design is based on combining the solar collector into a structural unit which doubles as that portion of the building roof. The installed unit is weather tight, insulated and readily maintainable. The concept is one which combines many of the most economic mass production manufacturing processes with inexpensive primary materials into a viable concept. Factory assembled cost predictions range from approximately $3.00 to $4.00 per square foot, based on large scale mass production and depending upon whether single or double glazed, or selective surface coated.

Figure 1 describes the basic concept of resistance seam welding mild steel sheets and pressure expanding to form the flow passages. The resulting collector has a low fluid inventory, approximately 0.2 lb/ft^2, with the majority of the absorber surface in intimate contact with the heat transfer fluid. This eliminates the conventional fin-tube heat transfer problem common to low thermal conductivity materials. Figures 2 and 3 describe the roll forming of the upper absorber sheet into a weather tight pan to hold the glazing and the lower sheet into a structural C-beam - all contributing to the overall section modulus of the collector. This design also results in a hot periphery for the glazing which produces a slight compressive stress edge effect in the glass to retard cracking. Figure 3 describes the joining of two collectors with a cap strip, forming a weather tight joint which, even in the event of glass breakage, would preclude water from entering the residence. Figure 4 schematically describes the collector installation as applied to a small residence.

Some of the cost effectiveness factors leading to the selection of steel for the parent material are shown in Table I. Steel is not only more energy effective in its basic raw material production, but is also the most cost effective on a deflection and strength basis. Table II shows properties of some prospective heat transfer fluids indicating that maximum collector equilibrium conditions can be permitted; however, the

*Work performed under the auspices of the National Science Foundation and the United States Atomic Energy Commission.

ethylene glycol would require slight pressurization. Since the polyglycol and paraffinic oils are non-corrosive, it is of particular interest that a corrosion free system might cost $.15 to $.38 per square foot of collector area based conservatively on .75 lb per square foot of fluid for a heat exchange type system.

The LASL test program was initiated in late 1973 with the testing of three resistance welded and pressure expanded flat collectors shown in the basic test frame in Fig. 5. Some test conditions and results are shown in Figs. 6 through 8. In general predicted and observed results are fairly good, even for transient conditions and cloud cover days of low insolation. Selected clear day data points, greater than 280 Btu/ft^2-hr are shown in Fig. 8. The double glazed collector panel No. 3 resulted in slightly low data points. Absorber material temperature distributions across the panel and at three axial stations are compared with fluid temperatures in Fig. 9. Panel No. 1 which had intentional manifolding at the ends, produced by increasing the end weld spacing, resulted in the best temperature distribution. Even the relatively poor distribution in the non-manifolded Panels 1 and 2, when integrating the area/temperature distribution, results in a very small performance degradation.

The ongoing program phases are as follows:

1. Testing of the two Tranter Manufacturing Co. flat collectors was started in late fall of 1974. These are modified as shown in Fig. 10 to include structural integration, foam insulation, extruded silastic seal strips, one single and one double glazed.

2. Setting up of a 40 panel collector array, Fig. 11, is targeted for completion in February 1975. This array will test fluid distributions, various sealing and venting arrangements, desiccants, and weatherability details. This test bay will serve as a full bay width prototype for the National Security and Resources Study Center Building (NSR) to be built at Los Alamos.

3. Figure 12 shows a preliminary architectural model of the NSR building and the collector array of approximately 8000 ft^2 for the 66,000 ft^2 floor area building. The architects, Charles Luckman Associates have devised an arrangement which has the mechanical equipment room located below the lower collector array and the upper collector array housing the cooling tower equipment. The building, now in the design phase, will contain both absorption refrigeration and a common-shaft Rankine turbine/vapor compression refrigeration unit.

Some of the surface coating evaluations in progress to evaluate prospective collector coatings are shown in Figs. 13 and 14. Some of the processing variables for the Harshaw Chromoynx black chrome and their effects upon solar spectrum reflectivity (or conversely absorption) and the thermal emission properties at 100°C are shown. Processing time in the electrochemical bath and the resulting oxide thickness is extremely important. Figure 14, Sample B-60, appears to be near the optimum processing time for this particular chemical bath and conditions. Figure 15 shows some equilibrium test results for single glazed 4" x 6" samples, used primarily for screening purposes, indicating the relative advantages of some of the selective surfaces. It is of interest to note the near cloud responses and enhancement. Some of the more prospective porcelain enamels, produced by Ferro Corp., which are extremely weather resistant and durable, have resulted in a solar spectrum absorption of .95. Thermal emissivity at 100°C for these porcelain coatings appears to be slightly less than .8. Testing of these surfaces for both reflectance and thermal emission was conducted by Sandia Labs, Albuquerque, NM.

TABLE I
MATERIALS COMPARISON

	MILD STEEL	STAINLESS (300)	ALUMINUM (1100)	COPPER
MODULUS OF ELASTICITY PSI	29×10^6	28×10^6	10×10^6	16×10^6
0.2 YIELD[1] STRENGTH, PSI	30,000	35,000	7,000	7,000
COST $/LB[2]	$.12	$.60	$.47	$.90
COST $/IN.^{3}[2]	.036	.18	.047	0.29
RELATIVE COST FOR EQUAL DEFLECTION	1	5.2	3.8	15
RELATIVE COST FOR EQUAL STRENGTH	1	4.3	5.6	35

(1) ESTIMATED PROPERTIES FOR MATERIALS SUBJECTED TO NORMAL FABRICATION TECHNIQUES FOR EACH. OTHER TECHNIQUES MAY PRODUCE DIFFERENT PROPERTIES.

(2) COMPARATIVE PRICES ONLY. THESE MAY NOT BE THE LATEST MARKET VALUES.

TABLE II
PROPERTIES OF SOME COLLECTOR COOLANTS

	UCON (POLYGLYCOL) 50-HB-280X	DOW THERM HP (PARAFINIC OIL)	85% ETHYLENE GLYCOL/WATER
VISCOSITY (CENTISTOKES)			
210°F	11.5	4.9	1.5
100°F	60.6	35.	6.5
0°F	2480.	--	93.
-20°F	9800.	--	--
DENSITY @ 60°F g/cm^3	1.04	.87	1.10
COEFF. EXP. PER °F	0.00042	.00054	.00034
THERMAL COND. BTU/HR-FT^2 °F/FT	0.119	.078	0.15
POUR POINT	-35°F	15°F	--
FREEZING POINT	--	--	-33°F
FLASH POINT	500°F	420°F	NONE
FIRE POINT	600°F	460°F	SELF EXTINGUISHING
BOILING POINT @ 760 mm	600°F	700°F	265°F
SPECIFIC HEAT @ 104°F (BTU/#/°F	0.46	.47	0.65
BULK COST ($/GAL)	4.40	1.40	2.35
SYSTEM FLUID COST/FT^2 COLLECTOR	.38	.15	.19

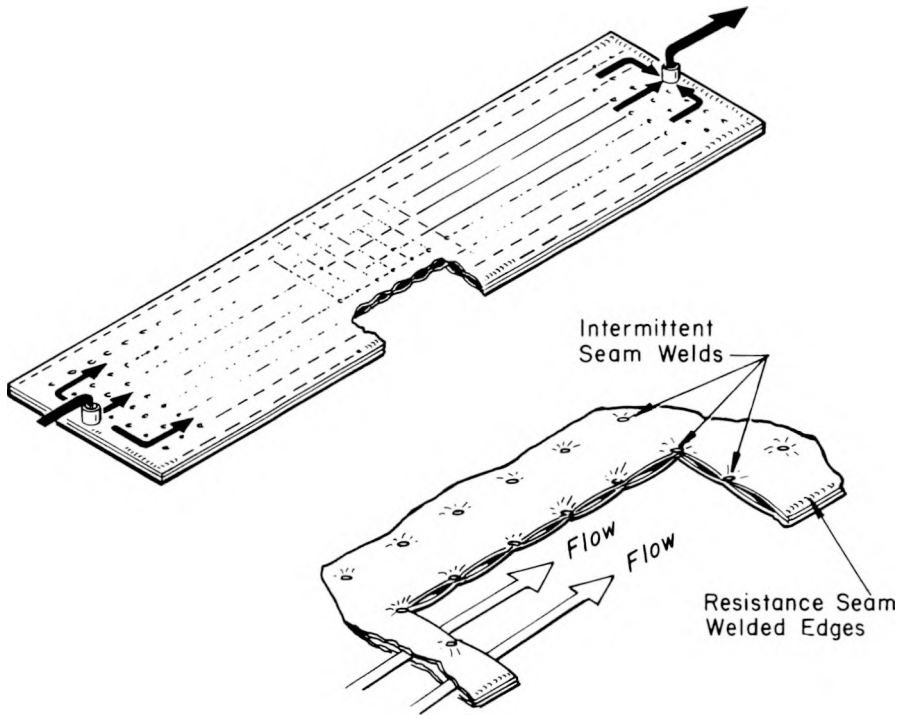


Fig. 1 – Expanded Metal Solar Collector Plate

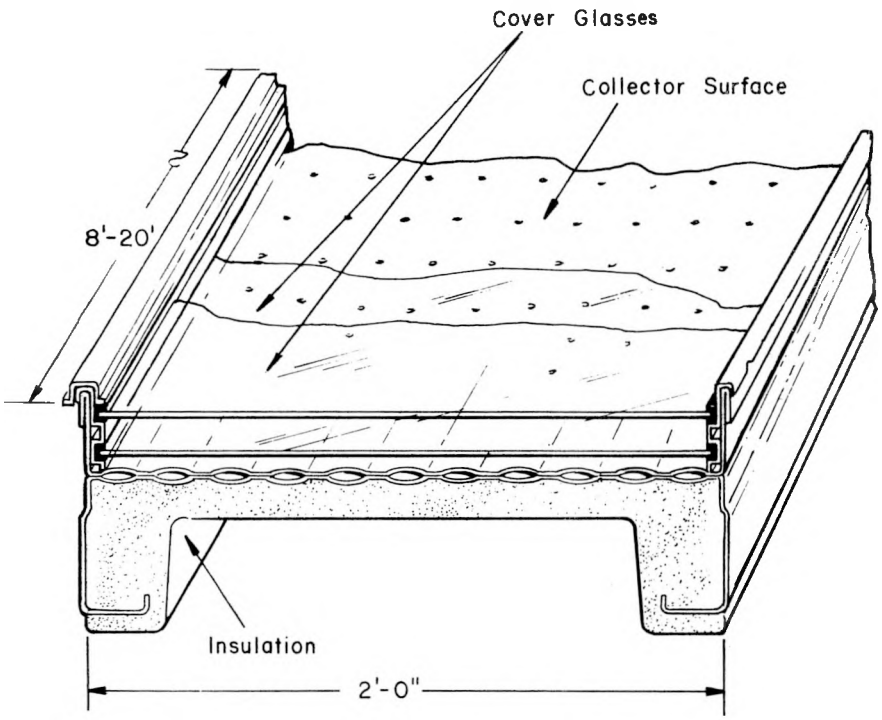


Fig. 2 – Structurally Integrated Solar Collector Unit

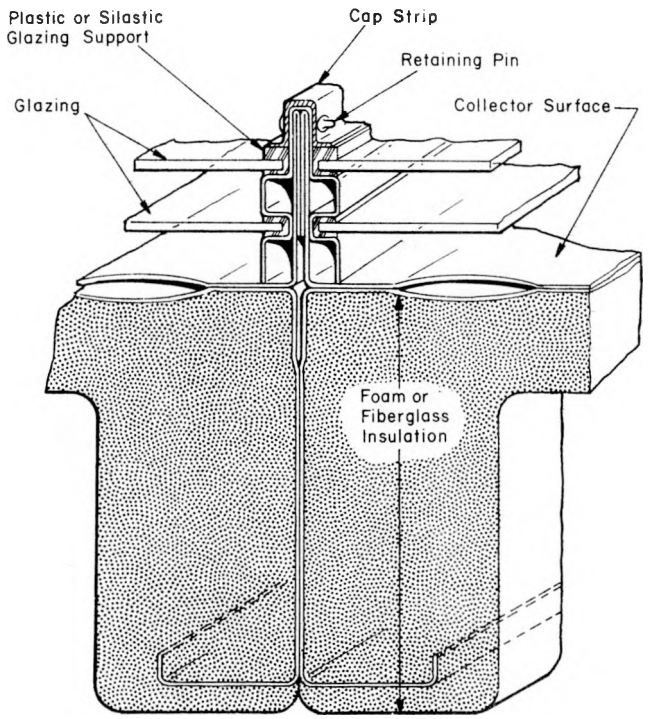


Fig. 3 – Detail Showing Fastening of Two Solar Collector Units

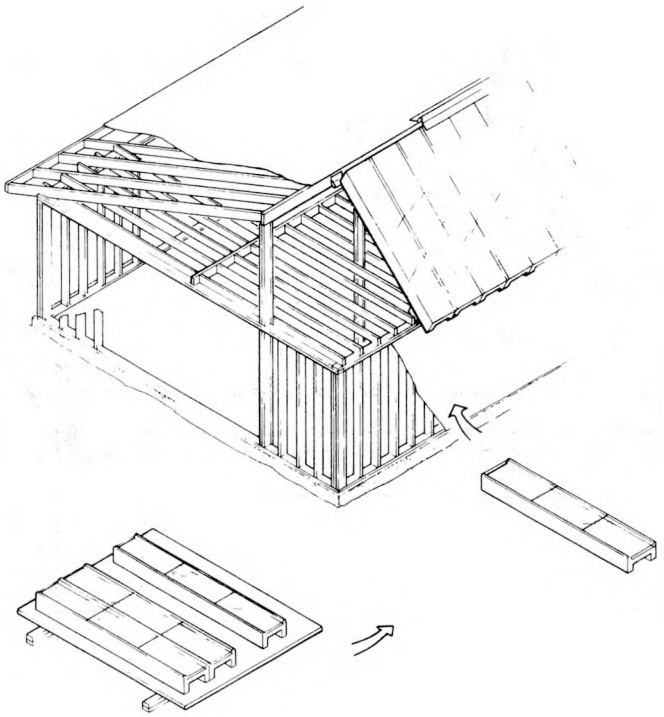


Fig. 4 – Typical Residential Application

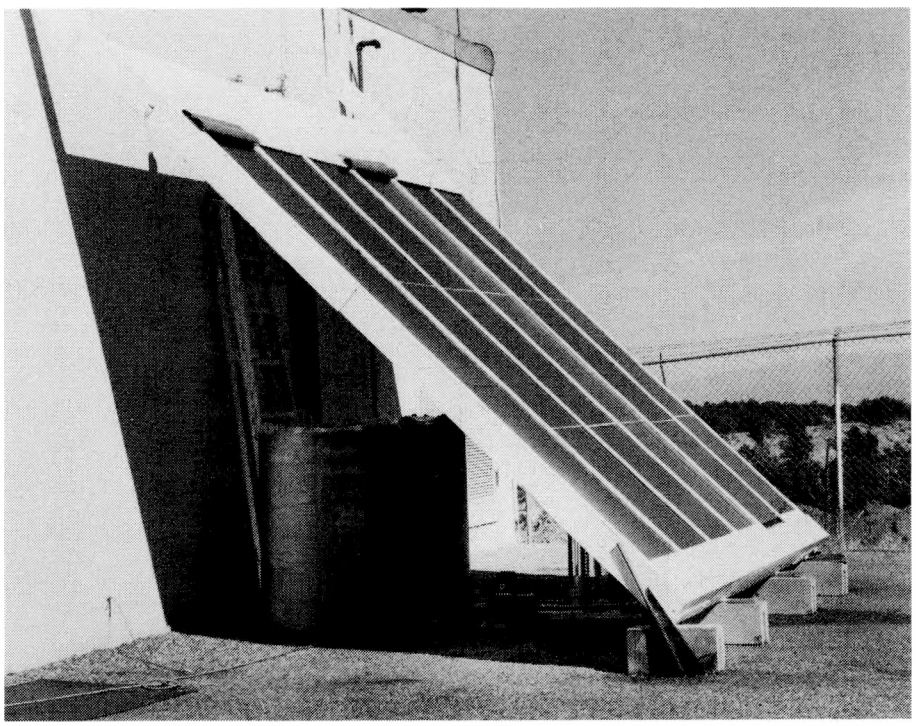


Fig. 5 – Initial Test Arrangement

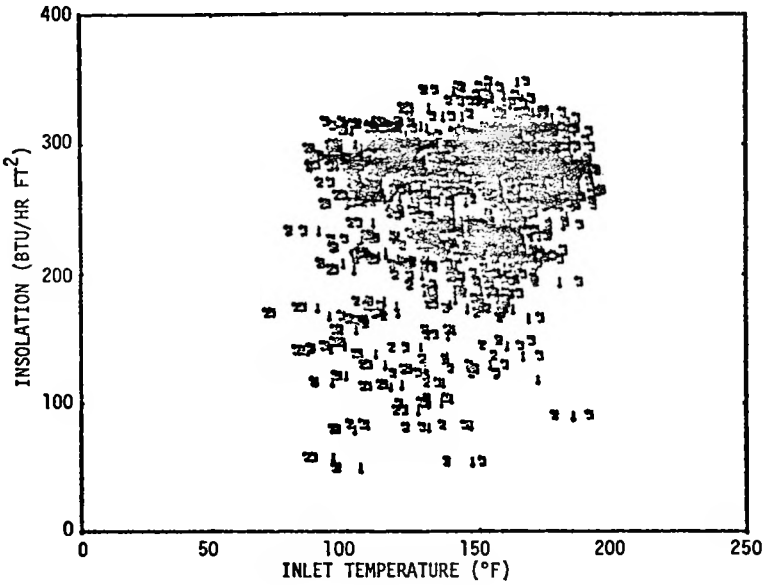


Fig. 6 — Range of Conditions for Data Taken Between March 1 and May 13, 1974

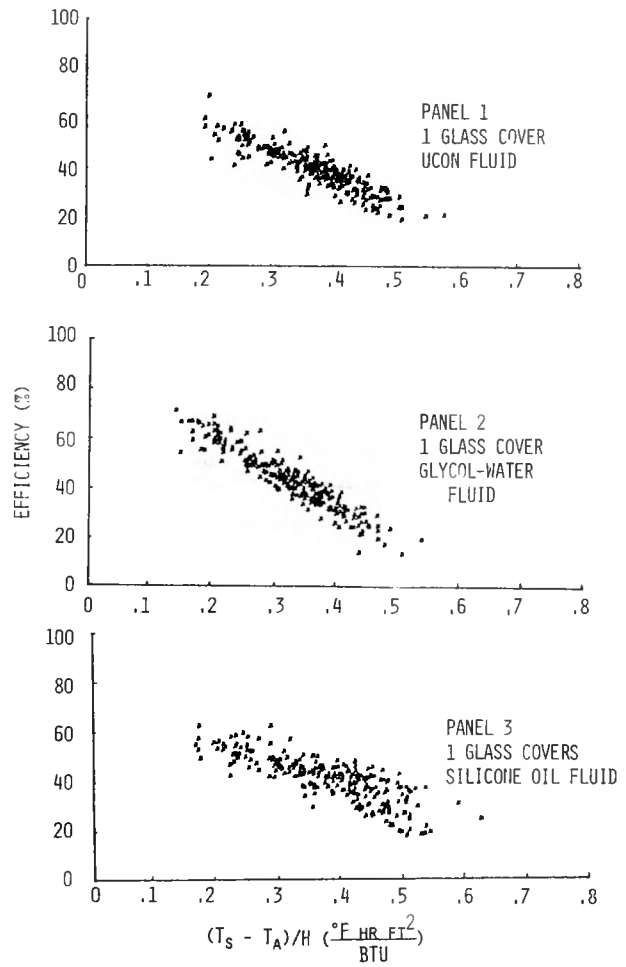


Fig. 7 — NBS Recommended Efficiency Plots for LASL Collector Tests

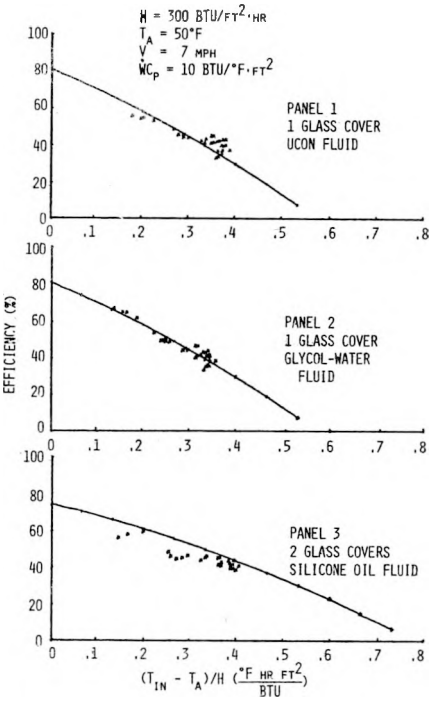


Fig. 8 – Efficiency Plots for Clear Day Data Base Line Conditions

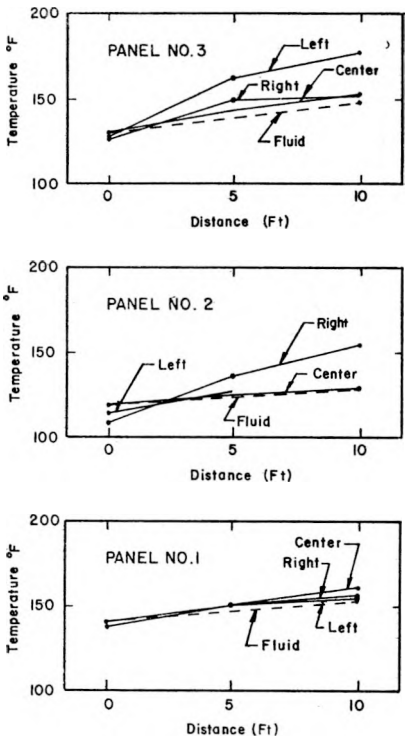


Fig. 9 – Test Panel Temperature Distributions

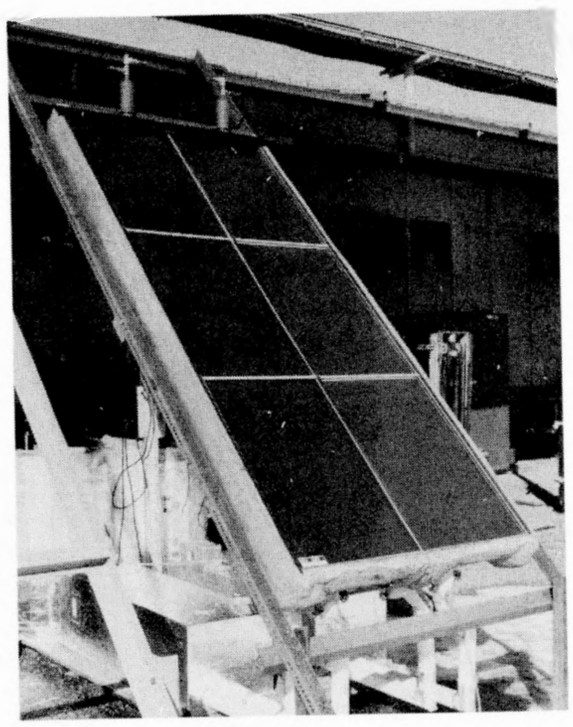


Fig. 10 – Tranter Modified Test Collectors

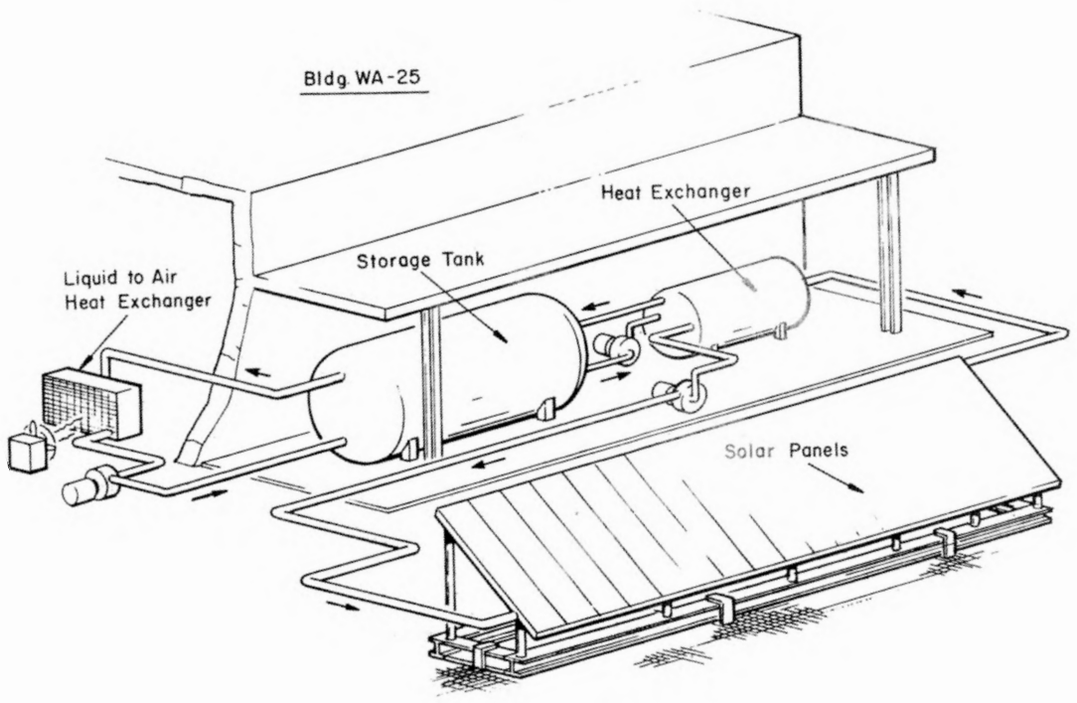


Fig. 11 – Collector Array Tests

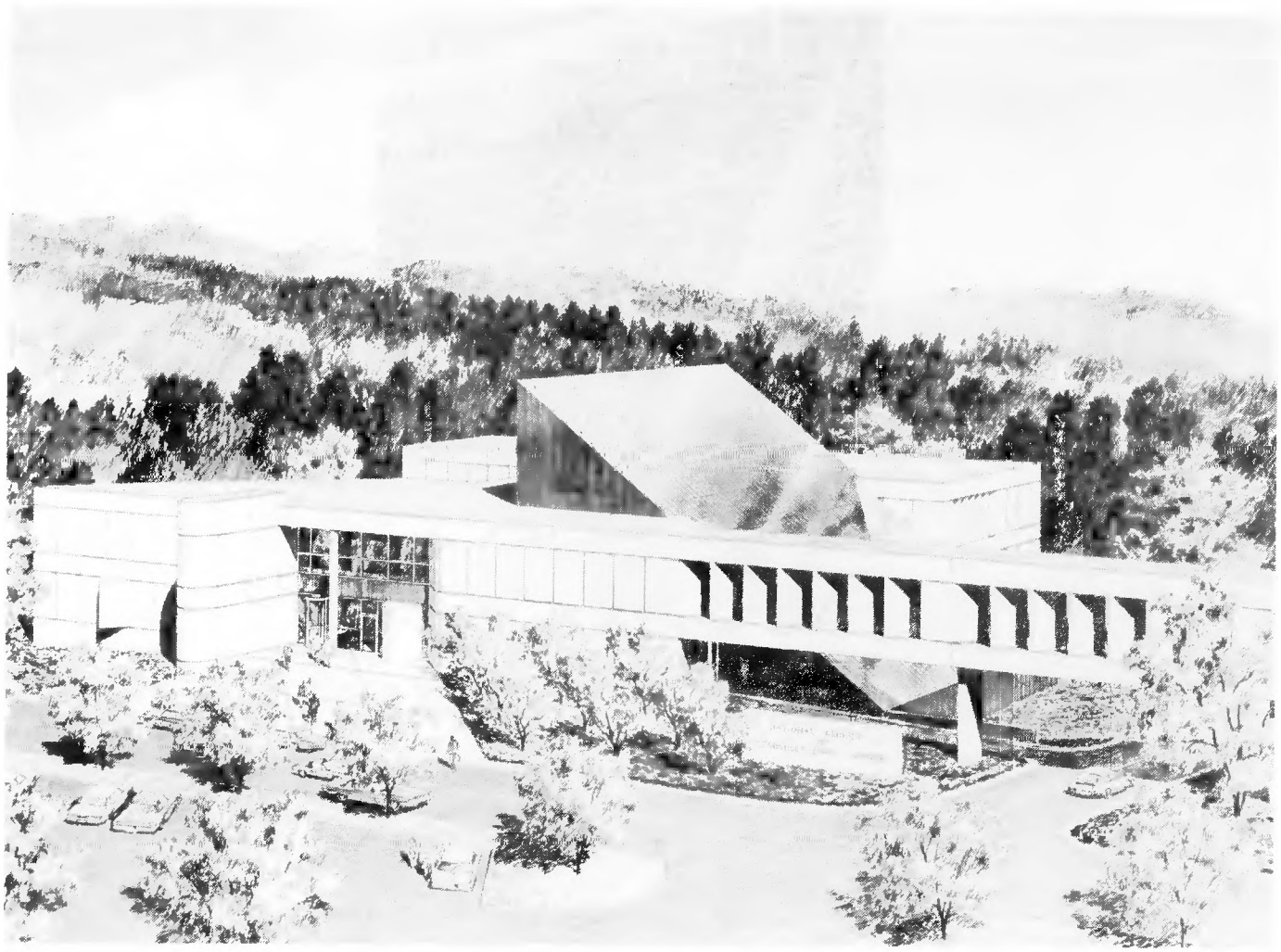
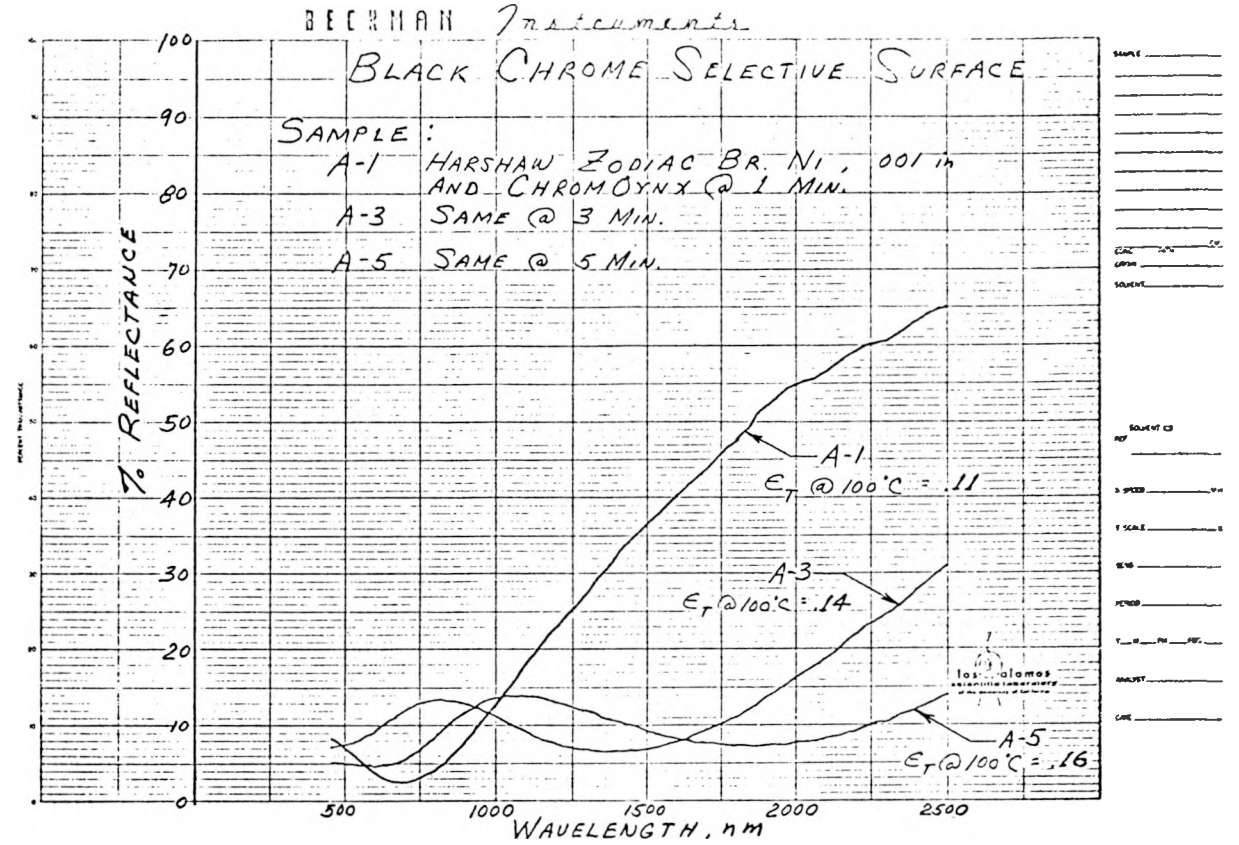


Fig. 12 – Model of National Security and Resources Study Center Building



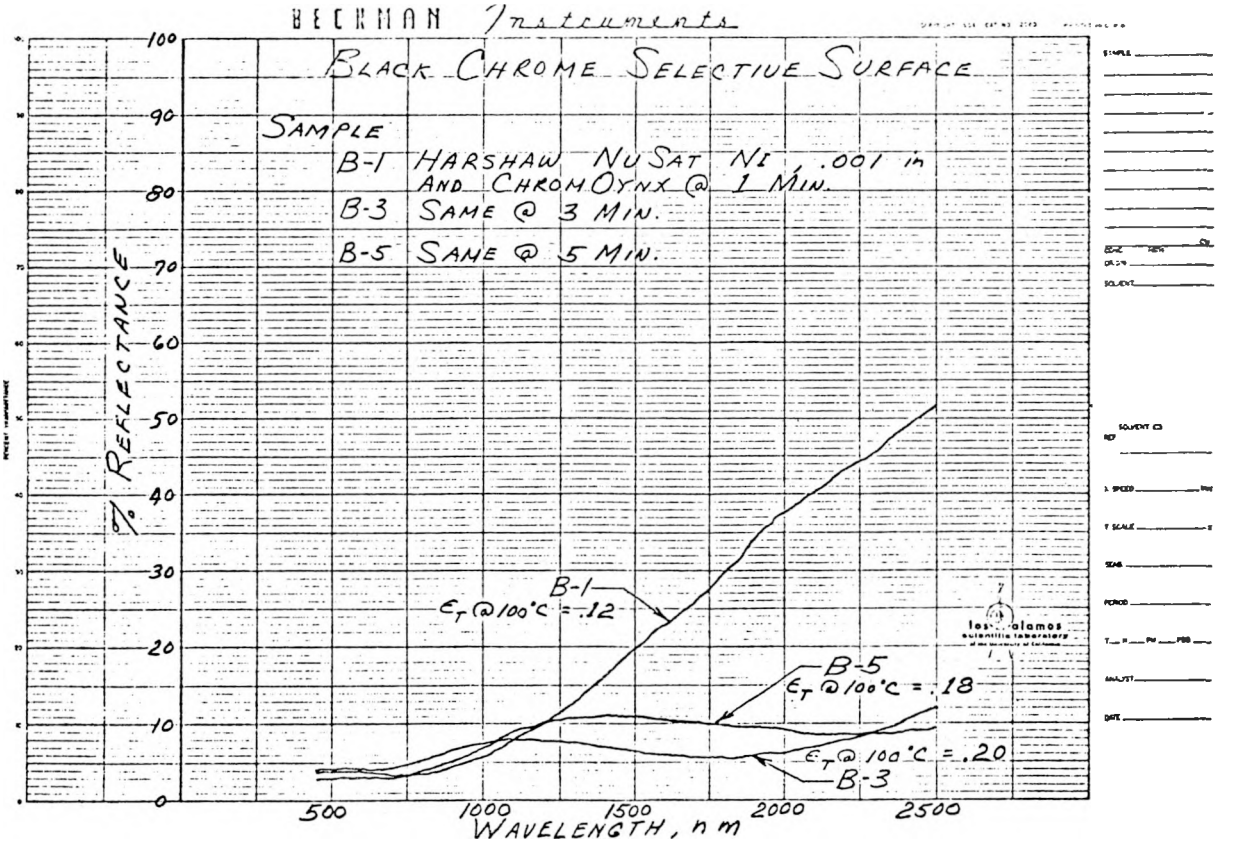
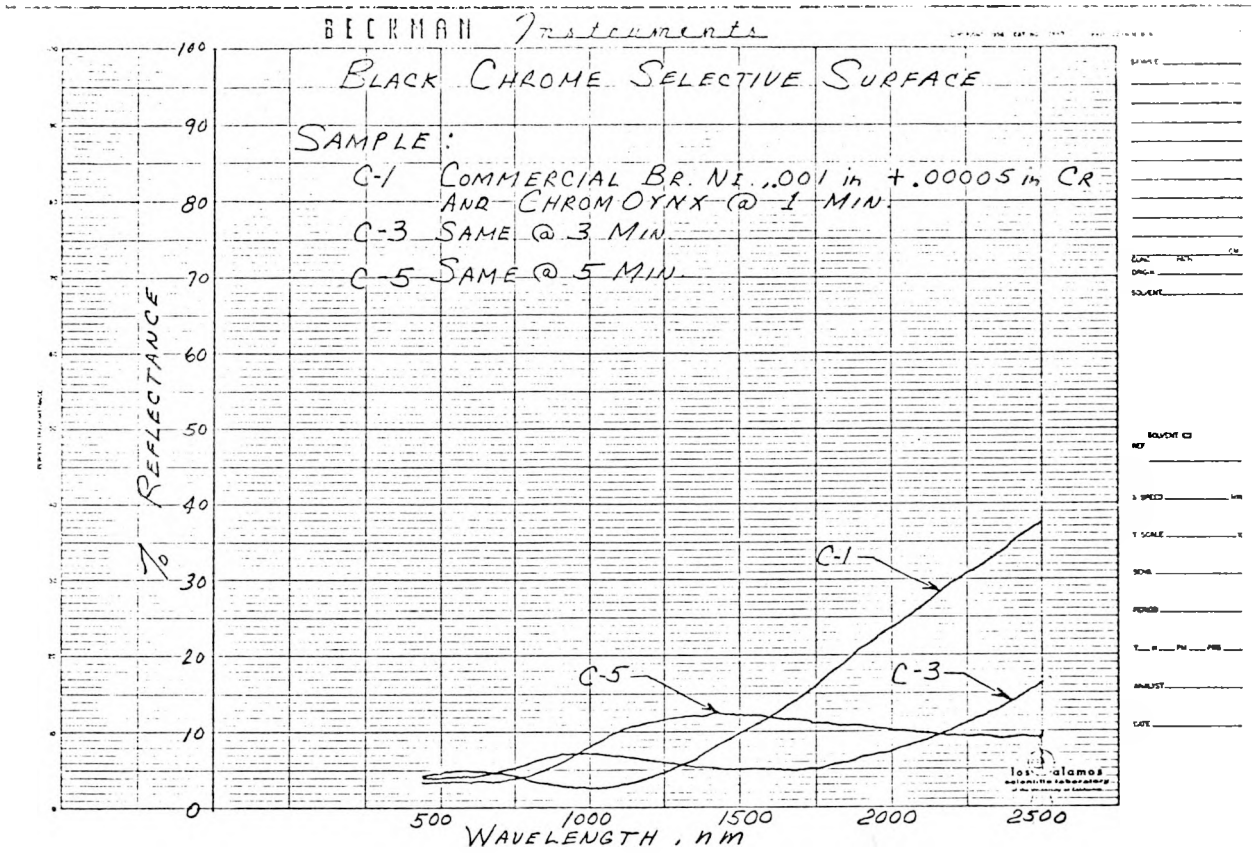


Fig. 13 — Black Chrome Selective Surface



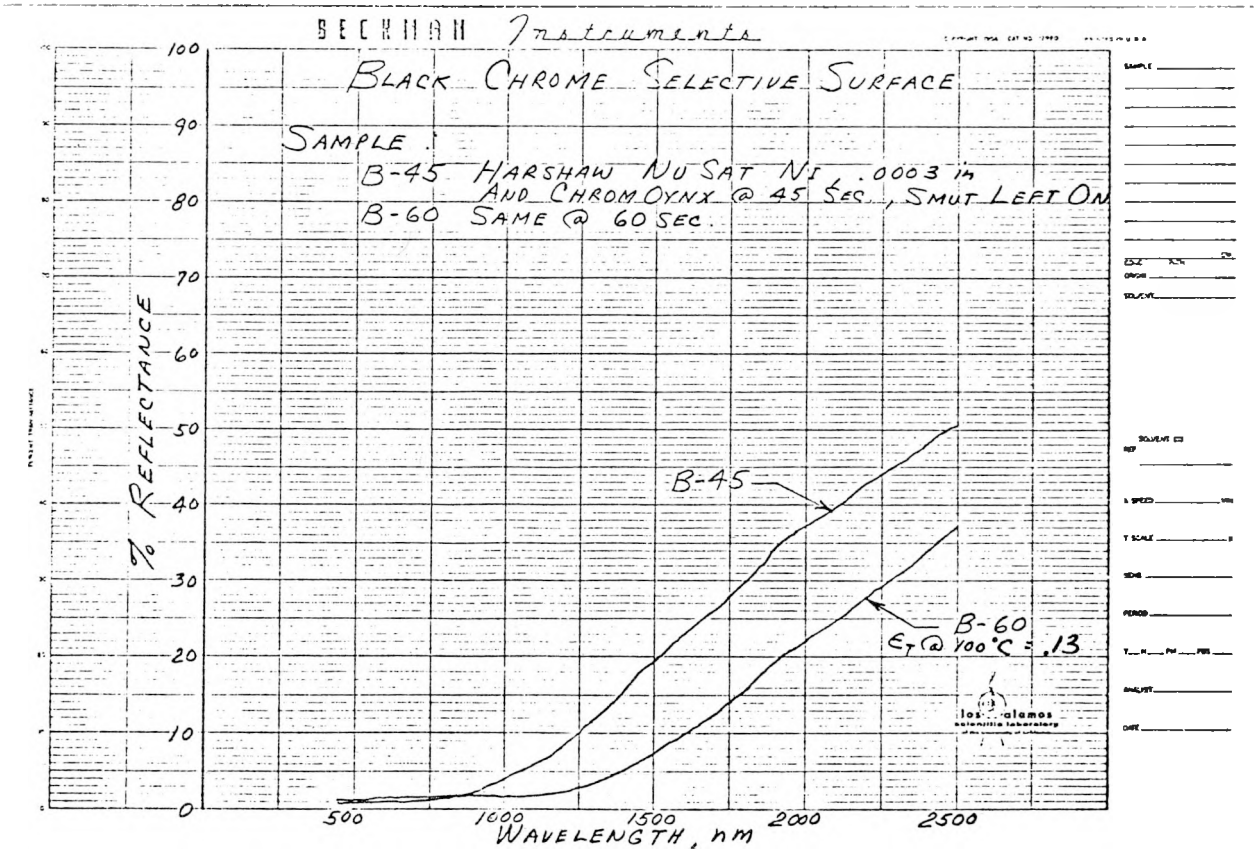


Fig. 14 — Black Chrome Selective Surface

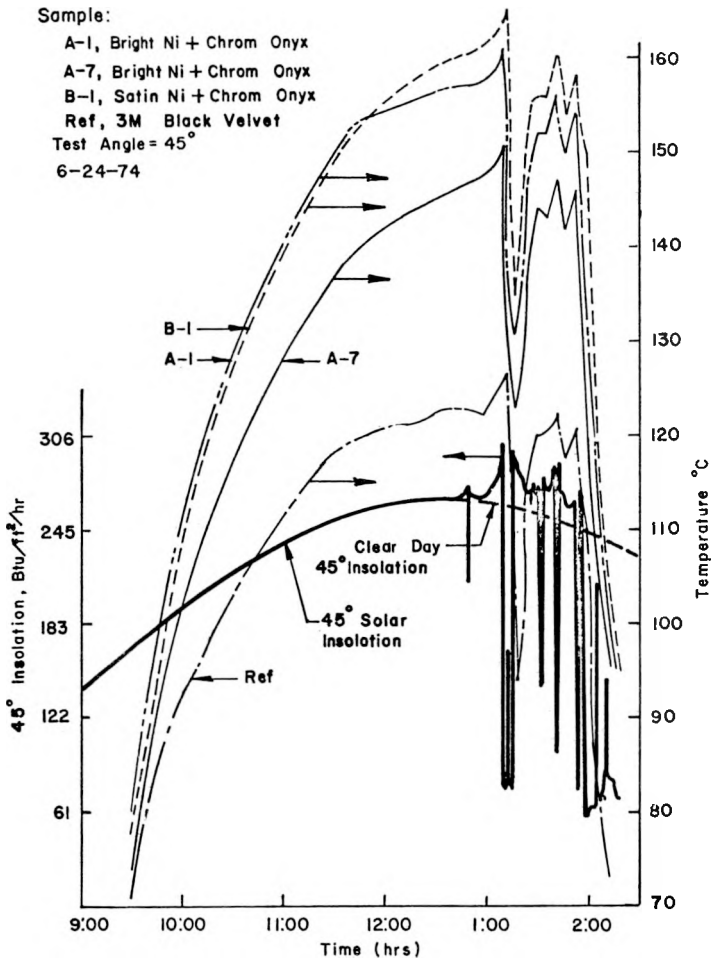


Fig. 15 – Selective Surface Equilibrium Test

DISCUSSION

Question (David L. Hartman, Dubin-Mindell-Bloome Associates): It is well known that urethane and styrofoam insulating materials either break down chemically or expand substantially at a typical collector stagnation temperature of 300°-350°. Is there some unknown reason why these materials would be suitable in the Los Alamos collector?

Answer (Stanley W. Moore, Los Alamos Scientific Laboratory): The particular urethane foam being evaluated is one that is CO_2-blown rather than the usual Freon-blown variety. Much data have been developed for the CO_2-blown varieties, which, as a result of the lower gas vapor pressure and higher permeability of CO_2 through urethane, have better dimensional stability. Samples have been tested in simulated solar equilibrium-type tests to 400° F. Although at these temperatures a dark brown to black foam resulted, the dimensional stability was extremely good with resulting mechanical properties adequate to serve the function as an insulating material. Bendix Corporation, Kansas City Division, has provided the basic formulation being studied and has conducted many tests that verify the dimensional stability of this foam.

52,077

COMPRESSED-FILM FLOATING-DECK SOLAR WATER HEATER

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The objective of this project is the testing and further development of the floating-deck heater. During the past year we have constructed two instrumented heaters, shown in Fig. 1, for overall performance testing. These heaters were not built to be economical but to provide accurate testing of the design concept. The heaters are equipped with thermocouples at various points on the deck surface and in the sump. The temperature of water from the sump is continuously measured to 0.1°F with a resistance thermometer. The air temperature below the water sump is controlled to eliminate bottom losses. During operation of the heaters, ambient temperature, wind velocity, and solar radiation are measured.

The floating-deck heater consists of a deck of insulation--preferably foam glass--floating on the heated water, Fig. 2. A compressing layer, that may be either transparent or the absorbing surface, rest directly on the insulation, and the glazing is situated above. Water flows in a thin film between the deck and the compressing layer.

The advantages of this heater are that it provides internal short term storage, it is simple and relatively inexpensive to build, and it can be built in large modules. It is also capable of rapid response to solar conditions as it has minimal thermal lag.

We have tested several combinations of compressing layer and glazing. These have been constructed in the form of sandwiches that fit directly on the floating deck. First we used two 3' x 3' panels of thermopane on the 3' x 6' deck. These were discarded because of generally poor solar transmittance and too much weight, and replaced by panels constructed of a blackened aluminum plate and either glass or plexiglass. The glass and plexiglass gave essentially indentical performance.

An optical efficiency was calculated from measured transmittance and assumed absorptivities for the black plate. The product of the optical efficiency and the incident radiation gives the absorbed energy. This value is compared in Table 1 with the sum of the heat loss, as calculated by the approximate formula of Hottel and Woertz, and the heat collected, as obtained by a heat balance, for a typical run. The weight of water in the heater is known, and its temperature is continuously recorded. This bulk temperature is used in the heat balance rather than the temperature rise across the heater, which is small and not easily measured.

The primary problem experienced with the experimental heaters has been vapor leaks. Various tapes were used to seal the glazing to the edge of the heater, but none has been satisfactory. We plan a different seal in our next larger units discussed below. Some water distribution problems were encountered because the compressing panels were too heavy. We changed from point entry to trough entry of the water which helped.

It became obvious that the problem of good water distribution becomes greater as the scale of the heater is increased. To study deck hydraulics we constructed a large shallow pond and floated a 10' x 20' deck on it with trough distribution. Using a light compressing layer, such as plastic film, greatly improved results, but it was still necessarily to carefully balance the deck. We also had trouble with air bubbles accumulating under the plastic except at high flow rates. Distribution was improved and air bubbles eliminated by raising the deck center a couple of inches as shown in Fig. 4.

Fig. 4 shows a possible configuration for the large heater we will shortly be building. The deck consists of 4" foam glass floating high in the middle with a plastic compressing layer, perhaps a laminated Korad, and 30 mil plexiglass as a glazing. Both these materials can be obtained in long rolls and unrolled on the deck.

Fig. 3. shows a proposed design for an 80,000 ft^2 floating-deck heater consisting of forty 10' x 200' modules. Fig. 4 is a cross section of a module. The total capital investment for this heater including the complete water circulation system is estimated to be \$3.11 per ft^2. This includes 15% profit and 10% contingency.

There are advantages in a large, central system serving many buildings. There are economics of scale, the individual buildings are freed from architectural restraint, and a central rather than individual back-up system may be used. The floating deck heater is ideal for this kind of operation.

In northern climates, the horizontal floating-deck heater could be used in conjunction with tilted heaters to provide storage. For single dwelling systems a tilted roof section could be combined with a flat roof floating-deck system to provide storage. Also reflection from the flat section would be intercepted by the tilted section.

TABLE I

Solar Heater Performance

May 27, 1974

Sun Angle	Radiation* - Btu/hr-ft^2 Total	Diffuse	Temperatures ^oF Heater	Air	Heat* - Btu/hr - ft^2 Absorbed	Collected	Lost(Hottel & Woertz)	Lost + Coll.
55.9	173.8	40	84.9	73.0	120	110.0	26.8	136.8
49.4	208.4	45	89.2	74.5	153	136.0	29.8	165.8
43.0	236.1	45	94.1	75.5	180	147.6	31.9	179.5
36.5	267.0	50	99.6	78.0	209	170.7	36.3	207.0
30.1	274.7	65	105.5	81.0	215	170.7	40.1	210.8
23.9	303.1	50	111.7	83.5	242	188.1	40.9	229.0
17.9	325.0	45	118.5	85.5	262	205.5	46.6	252.1
12.8	322.6	45	126.0	87.0	260	231.5	53.4	284.9
9.7	312.1	50	132.3	87.0	251	133.1	60.0	193.1
10.8	317.6	50	137.5	87.0	256	164.9	67.5	232.4
15.2	311.8	50	143.3	88.5	250	173.6	77.1	250.7
20.8	299.1	45	148.9	89.5	239	150.5	93.5	244.0
27.0	285.8	45	153.8	91.0	227	133.1	100.4	233.5
33.3	263.9	40	158.2	91.5	209	118.6	102.2	220.8
39.7	246.9	40	161.7	90.5	193	83.9	104.8	188.7
	4148				3266	2318		3229

$\frac{2318}{4148} \times 100 = 55.8\%$ Eff.

$\frac{3266 - 3229}{3266} \times 100 = 1.1\%$ Error

*All values are for 30 min so totals are double actual values

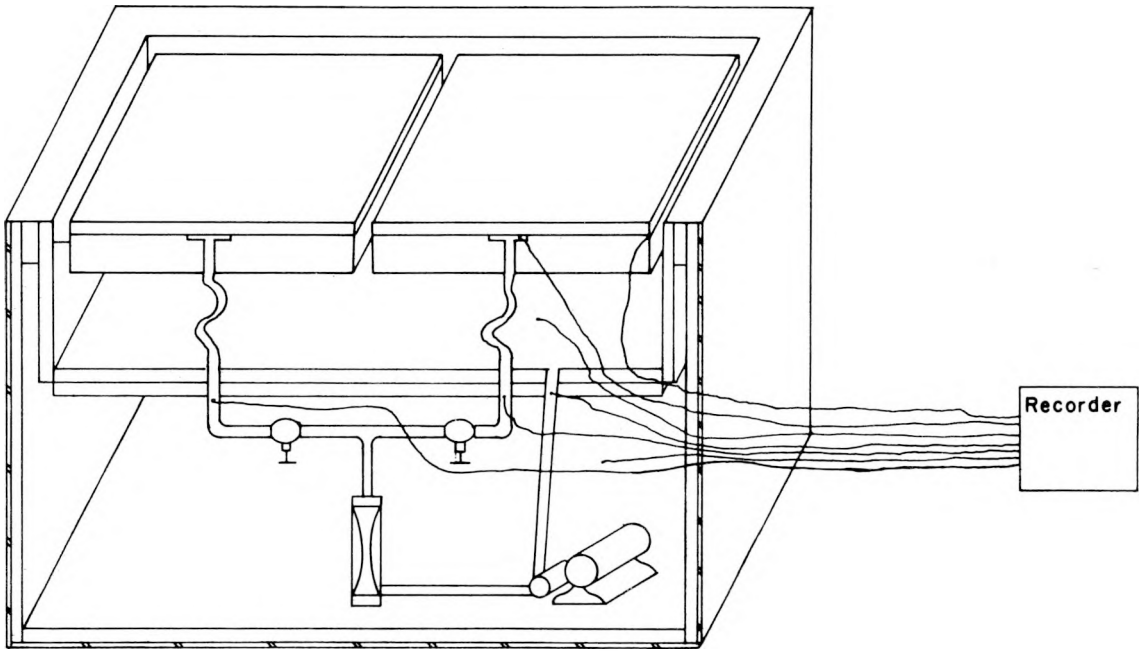


Fig. 1 – Experimental Heater

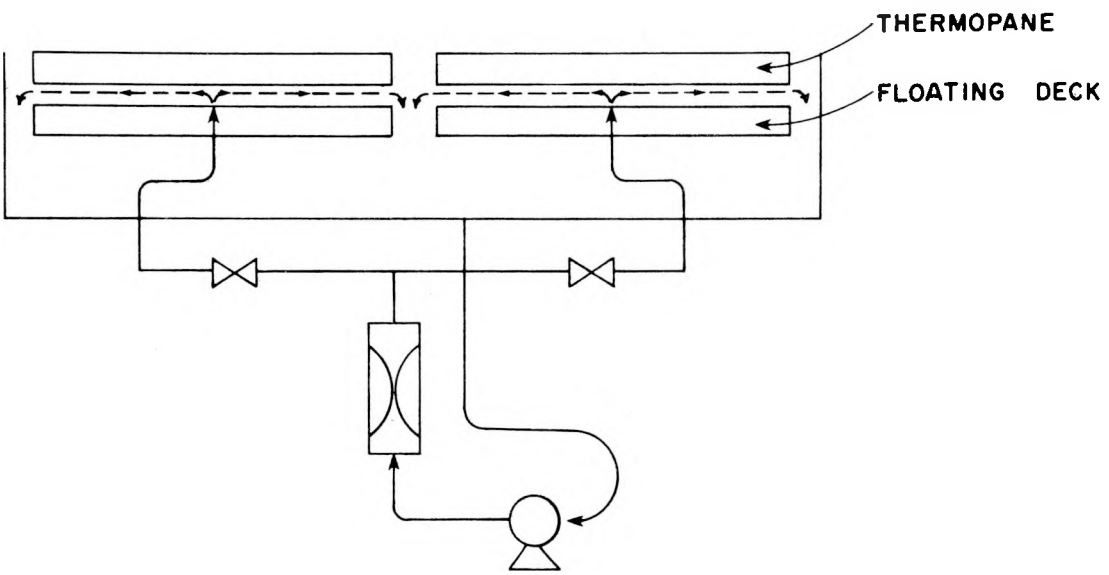


Fig. 2 – Schematic of Compressed-Film Floating-Deck Heater

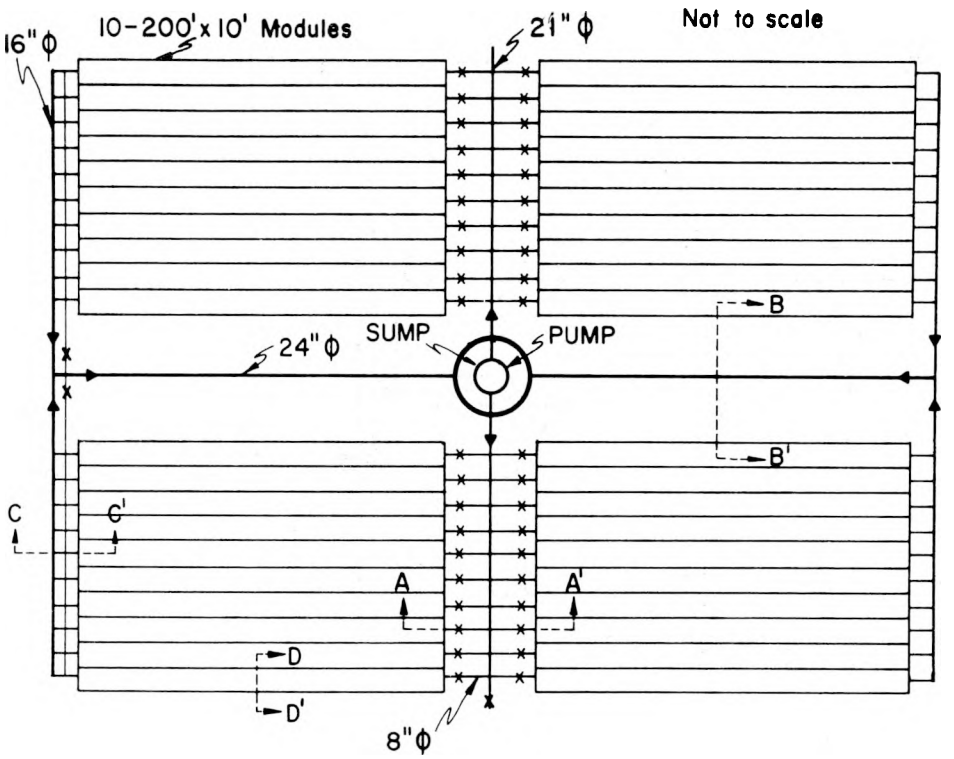


Fig. 3 — Large-Scale Modular Heater

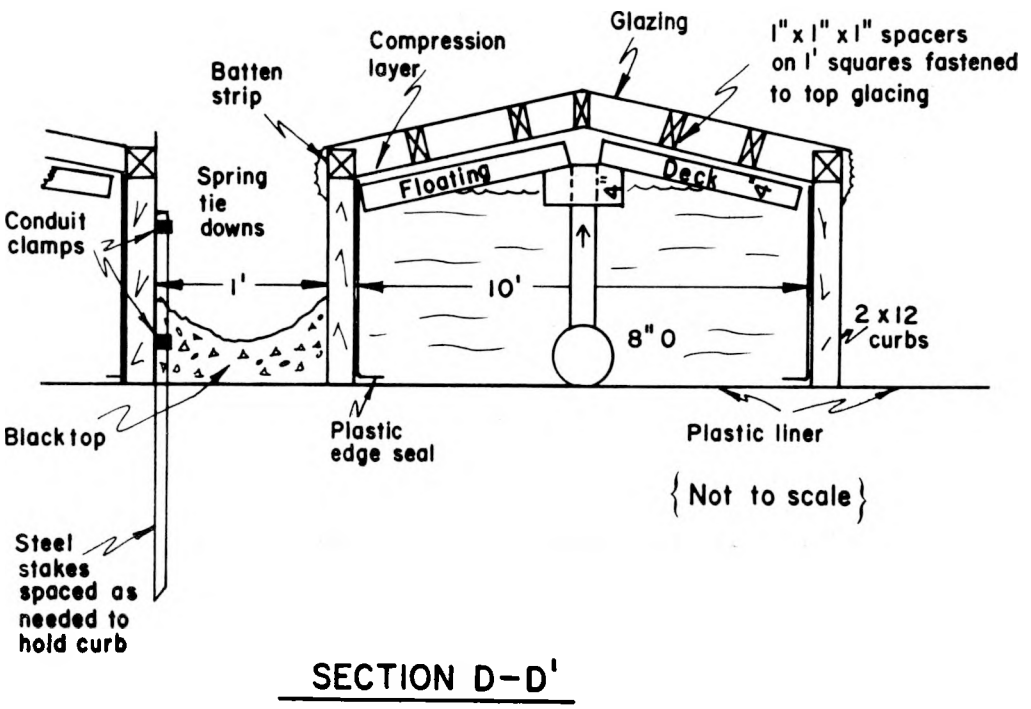


Fig. 4 — Cross Section of Heater Module

52,078

GLASS SOLAR HEAT COLLECTOR DEVELOPMENT*

R. B. Gillette, C. Deminet and W. D. Beverly
Boeing Aerospace Company
Seattle, Washington

This research program is aimed at developing a glass solar heat collector which avoids the use of a coated metal heat exchanger. The collector design studied up to the present time is shown in Figure 1. It consists of a glass structure containing vacuum cells and liquid passageways. The vacuum cells are individually sealed in the manufacturing process at the glass fusing temperature (about 1000-1200°C). Hence, a partial vacuum of about 1/4 atmosphere will exist at ambient temperature. The liquid passageways are interconnected in a labyrinth fashion as shown in the figure. Sunlight passes through the vacuum cells and is absorbed directly in a blackened liquid. Alternative approaches for absorbing sunlight include a blackened matrix suspended within the passageways, a blackened coating on passage walls, or absorbing glass walls. Work in the present program is concentrating on the concept of absorbing sunlight directly in a blackened fluid. It is presently planned to insulate the back side and edges with urethane foam, although it would be possible to insulate the back with an additional layer of vacuum cells as shown in Figure 1. This latter option provides the opportunity to illuminate on both the back and front surfaces, and also would allow the panel to be used as a variable transmittance wall.

The principal reasons for pursuing the development of a glass solar collector are low cost, and elimination of the need for large quantities of strategic materials such as aluminum and copper. Glass is inherently an abundant, low-cost raw material which lends itself to low production costs when highly automated. Automation of glass production does, however, require large capital investment. This fact will probably deter development of manufacturing facilities for glass collectors until the market for solar heating/cooling systems is well established. Another characteristic of glass is that its production is not energy intensive. Table I compares the energy consumed for producing a glass collector of the design shown in Figure 1, to that consumed in producing a conventional collector utilizing an aluminum heat exchanger. The estimated energy consumed for the respective designs is 36.3 x 10^3 BTU/ft^2 and 126.9 x 10^3 BTU/ft^2. At an assumed cost of \$4/10^6 BTU, the cost of energy to produce the collectors is 0.15 \$/ft^2 and 0.51 \$/ft^2, respectively. Accordingly, the glass collector should be substantially less sensitive to future energy cost changes than the conventional collector.

Additional advantages of the glass collector include: elimination of corrosion problems in the collector, elimination of moisture/condensation problems within the collector, and long-term environmental

*Sponsored in part by NSF Grant No. AER 74-09139.

stability. Potential disadvantages of the glass collector are that it requires development of a stable black fluid, or absorbing surfaces in fluid passages, and breakage could involve leakage of collector fluid. Another disadvantage of the collector design shown in Figure 1 is that it probably precludes the use of a high absorptance/low emittance absorber coating. Other glass collector concepts under consideration could, however, employ a selective coating.

Preliminary thermal performance analyses have been run on the glass collector shown in Figure 1. The mathematical model assumed in the calculations, shown in Figure 2, was evaluated with a general purpose thermal analyzer program. The overall calculation procedure involved selecting a desired fluid temperature, calculating the temperature distribution throughout the glass structure, calculating heat losses, calculating transmission and absorption losses, and then calculating solar collection efficiency for various angles θ and ϕ (Figure 2). This approach results in an instantaneous efficiency for a small segment of the collector, and ignores heat flow across cell walls and heat capacity effects. Results from these calculations are shown in Figures 3 and 4 in which collection efficiency is plotted vs. fluid temperature for various cell wall thicknesses W (0.2 and 0.4 cm) and heights H (1, 2, and 3 cm). Figure 3 assumes natural convection occurring in the "vacuum cells" at a pressure of one atmosphere, and Figure 4 assumes that a sufficient vacuum exists to eliminate natural convection in the vacuum cells. These calculations demonstrate that elimination of natural convection in vacuum cells provides significant benefits, cell wall height H is an important variable, and cell wall thickness W is a lesser-importance variable.

Activities planned for the existing NSF grant include thermal and structural design of several glass collector concepts, applications studies, fluid development studies, fabrication of prototypes, and conducting thermal performance tests on prototypes.

Table I. Comparison of Energy Requirements for Producing Solar Collectors

Collector Type	Component	Weight Lbs/ft^2	Energy Per Unit Weight BTU/Lb	Energy Per Unit Area BTU/ft^2	
Glass	Glass	5.70	*$5x10^3$	$28.7x10^3$	
	Polyurethane Foam	0.33	**23x	7.6x	
			Glass Collector Total		$36.3x10^3$ BTU/ft^2
Conventional	Glass (2 layers)	3.30	$5x10^3$	$16.5x10^3$	
	Aluminum Heat Exchanger	0.85	*100x	85.0x	
	Steel Enclosure	1.25	*20x	25.0x	
	Fiberglass Insulation	0.08	***5x	0.4x	
			Conventional Collector Total		$126.9x10^3$ BTU/ft^2

* Solar Heating and Cooling of Buildings (Phase 0), Volume II, Final Report Under NSF Contract No. NSFC-853, Report No. NSF/RA/N-74-022B, pp. 8-2, Table 8.2-1.

** Assumed equivalent to heating value of natural gas

*** Assumed equivalent to energy required to produce glass by "float process".

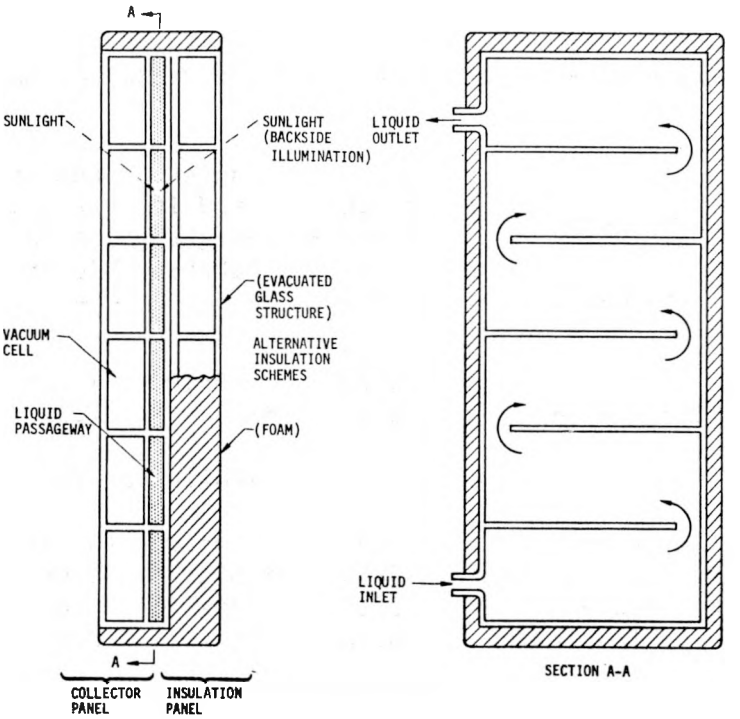


Fig. 1 – Schematic of Glass Solar Heat Collector

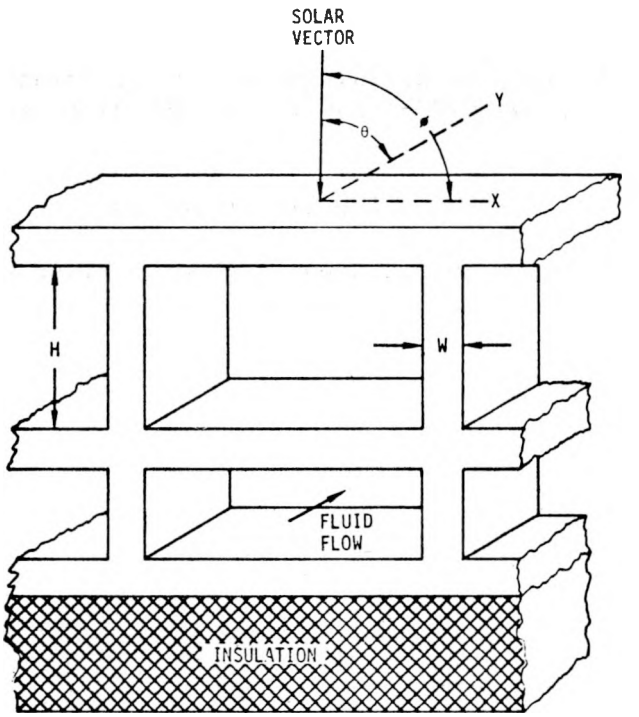


Fig. 2 – Thermal Model of Solar Heat Collector

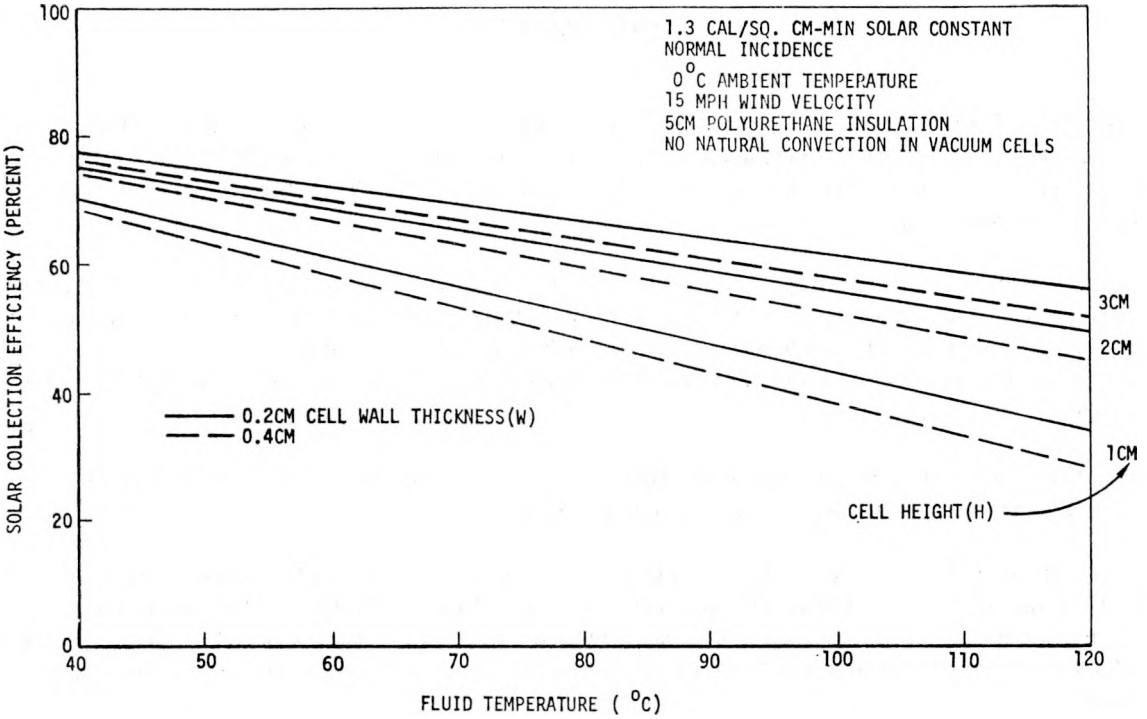


Fig. 3 – Efficiency of Glass Solar Collector without Natural Convection Occurring in Vacuum Cells

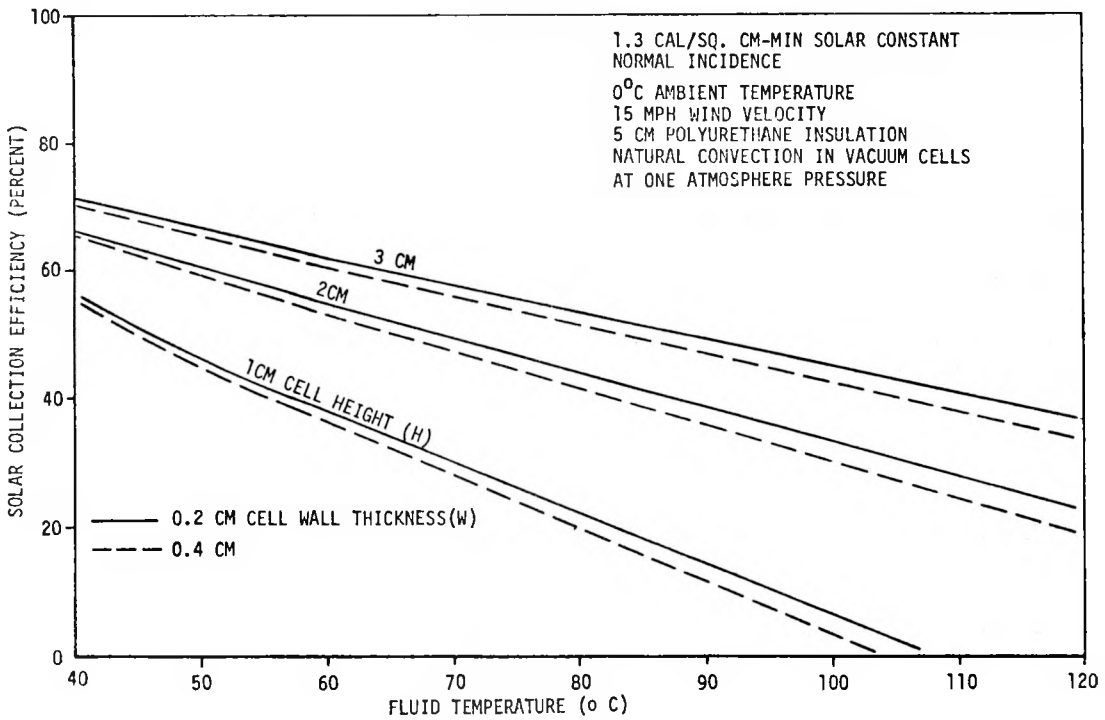


Fig. 4 – Efficiency of Glass Solar Collector with Natural Convection Occurring in Vacuum Cells

DISCUSSION

Question (Dan S. Ward, Solar Energy Applications Laboratory): Dr. Gillette stated that "A disadvantage of a vacuum glass collector is that it precludes high-absorptivity/low-emissivity absorber." Why? The Speyer tube (a vacuum glass collector) is ideally suited for use of a selective absorber. Only the Boeing design of using a black fluid precludes such use.

Answer (Roger Gillette, Boeing Aerospace Company): Dr. Ward is correct in his observation that all glass collector designs do not preclude the use of a selectively emissive coating. The particular Boeing concept presented at the meeting, if manufactured by a rolling-fusing process, will very likely not be amenable to application of a selective coating. Other designs and fabrication techniques for glass collectors could allow deposition of selective coatings.

Question (Francis DeWinter, Altas Corporation): How much heat generally gets lost through the glass Spacer-Standoffs, compared to that lost through the gas that it replaces?

Answer: At the present time we cannot provide a quantitative answer to Mr. DeWinter's question. A detailed thermal model of the collector is, however, presently being developed. Insertion of ribs between the glass plates induces a complex effect on heat losses; i.e., it increases conduction through the space occupied by the rib, decreases radiation heat flow between plates, and impacts gaseous convection and conduction losses in an uncertain manner.

Question (David Aronson, David Aronson Associates): Is it possible to apply vapor-deposited metal coating on glass instead of using absorbent liquid?

Answer: Yes, it would be possible in some manufacturing processes.

Question (Mr. Aronson): Can parallel cylindrical elements be used for vacuum elements?

Answer: Yes.

Question (Peter C. Green, W. R. Grace & Co.): What unfilled needs do you have in the "black fluid" area? What performance parameters are needed? How close are you to having these available?

Answer: A black dye is required for aqueous solutions that has long-term stability, high solar absorptance at low solution concentrations, and low cost. Black fluid tests conducted thus far under our NSF grant have shown that most dyes precipitate or lose their absorbing characteristic after long-term ultraviolet/high-temperature (about 130° F) exposure.

Question (Donald Lee Spencer, University of Iowa): Very high vacuums are required to produce the desired insulation effect. What vacuum levels are contemplated?

Answer: In the glass collector concept presented at the workshop, we anticipate a vacuum of about one-fourth atmosphere between the cover plate and fluid plate.

Question (Mr. Spencer): What dyes are being used?

Answer: Dyes being tested include carbon particle suspensions, organic molecular dyes, and metal oxide particle suspensions.

Comment (Mehmet K. Selcuk, Jet Propulsion Laboratory): A similar concept was brought to the attention of Corning Glass Works, but was not considered due to the relatively large research funds needed. The evacuated tube ultimately must be a multibore tube of oval shape. Integrating the absorber and cover and bonding the glass would result in serious cracking problems. It seems to be more practical to use a conventional metal absorber completely separated from the glass cover.

52,079

EVALUATION OF THE SOLAR BUILDING, ALBUQUERQUE, N.M.

Stanley F. Gilman

The Pennsylvania State University

University Park, Pa. 16802

The award grant for this project resulted from the 1973 National Science Foundation Solar Energy Research Solicitation Program under the category, "Evaluation of Existing Buildings." The grant award was effective April 1, 1974, so efforts to date have primarily been to ready the building for evaluation during the forthcoming winter heating season.

A photograph of the Solar Building is presented in Fig. 1. The flat-plate water-type solar collector faces due south and is tilted back 30 degrees from the vertical. The collector forms the south wall of most of the building, which is an important economic aspect. The collector is comprised of 55 individual panels, all 22 in. wide, with approximately half being 9 ft high and the other half being 7 ft high.

This commercial office building was constructed in 1956 by the owners, Bridgers and Paxton Consulting Engineers, Inc., and since that time has been owned and occupied by the firm. In 1956, it was the first known solar-heated office building in the world.

The building has a heat pump assisted solar energy heating system which was designed by the firm for its own evaluation of the potential of solar energy The principal elements of the system serving 4300 sq ft of single story office space are the 750 sq ft solar collector, a 6000 gallon underground water storage tank, one water-to-water heat pump and five water-to-air packaged heat pumps.

Operating data were collected during the winter of 1956 - 57 and the results presented at the January 1958 Annual Meeting of the American Society of Heating and Air-Conditioning Engineers. This paper, "Performance of a Solar-Heated Office Building," by F.H. Bridgers, D.D. Paxton and R.W. Haines was published in the ASHAE Transactions section of the November 1957 issue of Heating, Piping & Air Conditioning.

The conclusion of the authors at that time was that, in view of the low cost of energy, the economics were unfavorable for such systems. With the advent of the energy crisis and the escalating costs of all forms of energy, the economics today are fast turning around.

The solar collector portion of the system was operative until about 1964, at which time it was by-passed and hence no longer used. The reason for this was that it required some manual attention and operation, such as draining the collector in advance of predicted freezing weather.

The principal objectives of the current NSF project are:

1. Refurbish the system and get it operational again. In this regard, an ethylene glycol-to-water heat exchanger, pump and piping system have been added to eliminate the freeze-up problem.

2. Thoroughly instrument the system and collect winter heating data with a computer data acquisition system at the site.

3. Transmit operational data to the Pennsylvania State University computer for analysis.

4. Correlate actual performance with computer predicted performance.

5. Develop generalized design and costing data for designers to use, and publish it in forms such as ASHRAE papers and the ASHRAE Handbook.

The current status of the project is that the data acquisition system is operational and the first data are now being transmitted to the Pennsylvania State University.

Other than the usual problems of equipment and instrumentation delivery and start-up "bugs," the one major problem involved the solar collector. When selected collector panels were removed and examined, it was discovered that deterioration of the panels over the years had been greater than anticipated.

The original collector panels were aluminum "Roll-Bond" panels through which water was circulated. Due to corrosion, many leaks developed. Consequently, copper tubes were soldered to the original aluminum panels in place of the water circuit through the aluminum panels.

A photograph of the solar collector taken from the southwest is shown in Fig. 2. In the lower right corner is a typical collector panel. One is also shown on the ground beneath the main solar collector.

Those of you familiar with materials will recognize that the bonding of copper tubes to aluminum sheets is a difficult task. When the initial inspection of a few of the panels was made, both bond failures and copper tube failures due to freezing were discovered. This made all 55 panels suspect. Consequently, all were removed, inspected, repaired if necessary, tested and replaced.

Repair procedures varied with the problems. Simple bond failures were repaired by re-soldering the copper tube to the aluminum panel. Tube failures due to bursting of the tubes caused by freezing of trapped water were repaired by removing the tube. A new tube was then installed by fixing it to the panel with metal clips and bonding it to the panel with an aluminum epoxzy compound, as shown in Fig. 3.

When repair was completed, each panel was leak tested with 30 psig air before being replaced in the main collector assembly.

As there was concern about the effectiveness of the aluminum epoxy bond, an outdoor test rig was developed and constructed. One of the original panels that showed no deterioration was tested side-by-side with a completely refurbished panel with replaced copper tubing and aluminum epoxy bonding compound. At equal water flow rates, the temperature rises of the two panels were essentially identical, indicating similiar solar energy collector performance. These tests provided assurance that the repaired panels would operate effectively.

Also, one section of original panels was replaced by four all copper panels of current manufacture and instrumentated for special tests during the 1974-75 winter heating season.

In summary, deterioration of the solar collector panels presented a unique and difficult problem. However, effective repairs were made and confirmed by test, and winter heating operating data are now being collected and analyzed.



Fig. 1 — Solar Office Building in Albuquerque, New Mexico

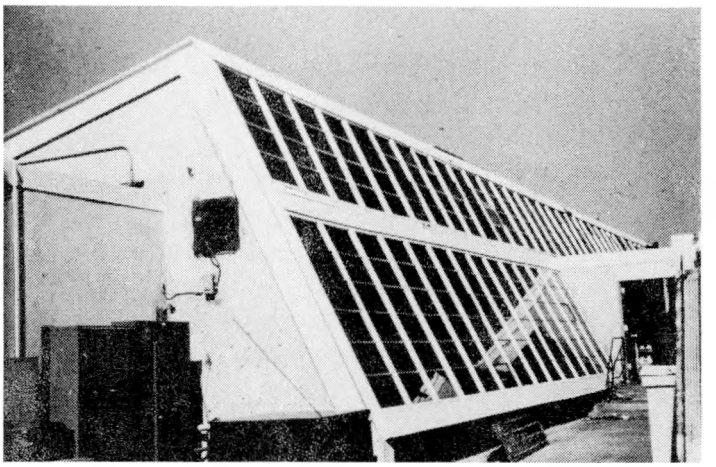


Fig. 2 — View of Solar Collector Array from the Southwest

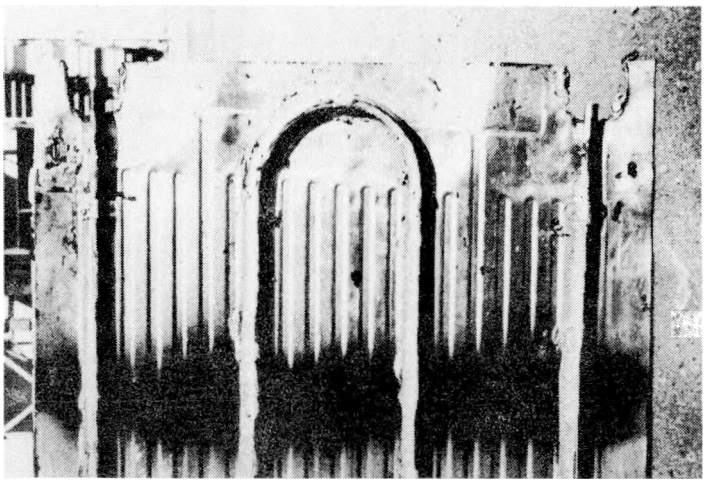


Fig. 3 — Detail of Tube Bond to Collector Plate

DISCUSSION

Question (John S. Best, Dow Chemical Company): What is your proposed method of using the solar energy to supplement the heat-pump cycle? What C.O.P. do you expect to achieve?

Answer (Stanley F. Gilman, Pennsylvania State University): We don't expect to supplant the heat-pump cycle. The heat-pump cycle allows us to take a storage temperature for usable heat down to about 40° F and then pump this energy up and make useful 100° F heat to heat the space. As far as C.O.P.'s are concerned, we expect to achieve a C.O.P. in the range of 4.0 to 4.5.

Question (Erik A. Granholm, Bendix Aerospace Systems Division): Was there a thermal performance comparison made, or available, between the Roll-Bond® collector and the aluminum-plate/copper-tube collector?

Answer: No. In about 3 months, corrosion caused leaks in the aluminum Roll-Bond® collectors. They were abandoned and not tested further.

SESSION 2

FLAT PLATE AIR HEATING COLLECTORS

Start here
52,080

LONG TERM (16 YEARS) PERFORMANCE OF AN OVERLAPPED-GLASS PLATE SOLAR-AIR HEATER

J. C. Ward

Solar Energy Applications Laboratory

Colorado State University

Fort Collins, Colorado 80521

Objectives of This Project

The main objectives of this project are as follows:

1. To determine the change in efficiency of a flat plate solar collector over a long time period of continuous operation with no maintenance.
2. To determine the cost required to restore this efficiency.
3. Observe the operation of the collector after repairs have been made to determine the restored efficiency.
4. Determine the amount of hot water energy furnished by this type of solar system.

Duration of This Project

The duration of this project is 2.75 years, but only the first year (and objective number one above) have been funded so far.

Research Plan

The long-term performance of a residential solar heating system is being determined for a solar heated system which has been operating continuously for sixteen years with no maintenance. This residential solar heating system is the Colorado Solar House located in Denver, Colorado, and designed and operated by Dr. George O.G. Löf. The performance of this system was determined during the 1959-60 heating season, and the results were reported in two masters' theses and a paper (reference 1). Some of the performance data published in this paper are shown in Figures 1 and 2.

The performance of this system is being redetermined during the present 1974-75 heating season so that changes in efficiency occurring during a period of 16 years can be observed. The system has operated continously since it was first installed in 1957 with no maintenance. Therefore, comparison of the data obtained during the two heating seasons will yield information regarding the rate of change of efficiency of solar collectors. Also, information is being obtained on the hot water heating system which is also solar heated.

The solar collector is an overlapped-glass plate solar-air heater type which has been discussed in an article by K. Selcuk (reference 2). The cross sections of this collector are shown in Figure 3. Empirical analysis of the data calculated and experimentally observed by Selcuk indicates the following 2 equations (both with a correlation coefficient of better than 0.99) may be appropriate over a limited range of values:

$$\Delta T = a + bV \qquad (1)$$

and

$$\% = \alpha + \beta \frac{1}{V} \qquad (2)$$

where ΔT is the temperature rise in the air when passing through the collector (^{o}F), V is the velocity of air through the collector (fps), % is the collector efficiency, and a, b, α, and β are constants for a given collector and set of conditions. For Selcuk's collector and conditions, the values of a, b, α, and B respectively were:

$76.4^{o}F$, $-15.4\frac{^{o}F}{ft/sec}$, 95.6%, and -48.7 ft/sec.

Temperature observations are being made by means of 20 thermocouples whose outputs are continuously recorded on two multi-channel recorders. Solar radiation data is integrated and printed out on an hourly basis and is measured as that energy incident on a surface with a slope of 45 degrees from the horizontal, which is the same slope as the solar collector. In addition, daily observations are being made of the amount of hot water used, the quantity of electricity used by the single blower in the system, the electricity used in the home, gas used by the auxiliary furnace, and gas used for hot water heating. It is believed that the bulk of electricity used in the home is eventually converted to heat.

Accomplishments to Date

All of the instrumentation needed for the project has been received, repaired, calibrated, and installed. All of the instrumentation and equipment is currently satisfactorily operating. Data for October and November has been obtained, and the October data is currently being analyzed. December data is currently being collected.

Problems Already Encountered and Expected

The National Science Foundation's official starting date for this project preceded actual official written notification by one month. Delivery of the new Eppley Pyranometer took 3-1/2 months. One of the multi-channel temperature recorders malfunctioned for a few days in October because of excessive case temperatures. These excessive case temperatures were caused by following the manufacturer's instructions, "In order to minimize the entrance of dust and dirt it is recommended that all unused conduit holes be closed with the plug buttons supplied with the instrument". The overheating problem was completely resolved by removing all the plug buttons. However, there is the chance that dust and dirt may cause problems later.

Relationship of This Project to the Overall U.S. Development Effort in Solar Energy for Building Heating and Cooling

The lifetime, rate of depreciation, rate of change of efficiency, and maintenance costs of solar collectors must be known in order to optimize solar system design and operation. The costs of solar energy must be known on an annual basis for comparison with other energy sources and also so that the proper economic balance between solar energy and auxiliary energy can be reached in design.

Present Condition of the Collector

Figures 4, 5, and 6 indicate the present condition of the collector.

References

1. "Design and Performance of Domestic Heating System Employing Solar Heated Air-the Colorado Solar House," by George O.G. Löf, M. M. El Wakil, and J. P. Chiou, published in the Proceedings of the United Nations Conference on New Sources of Energy, 1964, pages 185-197.

2. K. Selcuk, "Thermal and Economic Analysis of the Overlapped-Glass Plate Solar-Air Heater," Solar Energy, Volume 13, pages 165-191, 1971.

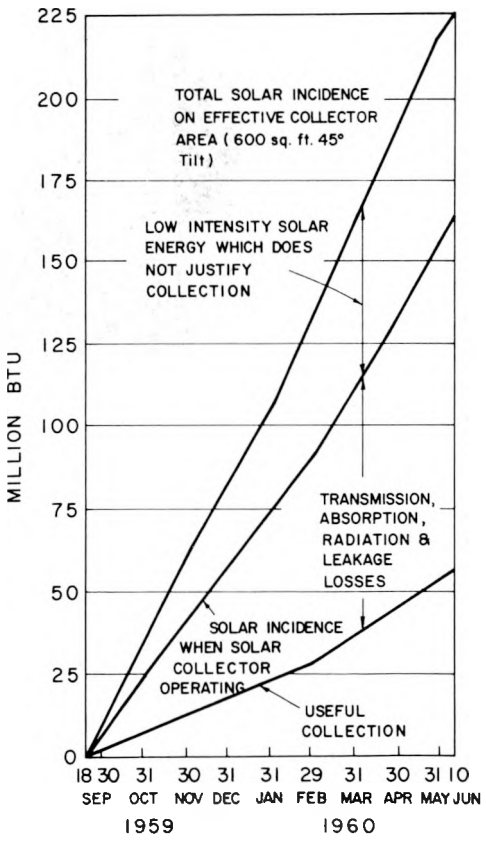


Fig. 1 – Cumulative Performance Data

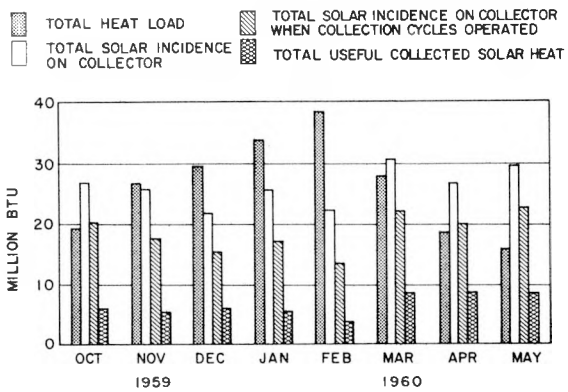
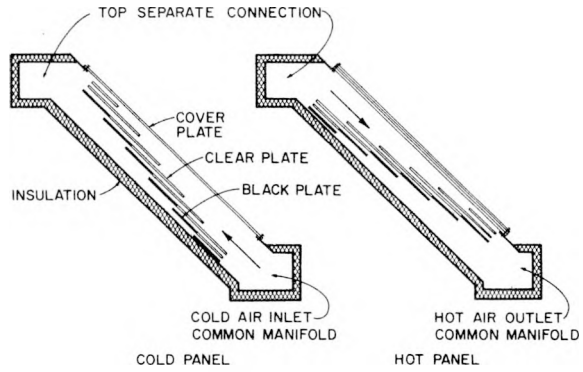


Fig. 2 — Monthly Performance Data



Cross Sections of Collectors
(NOT TO SCALE)

Fig. 3 — Cross Sections of Collectors

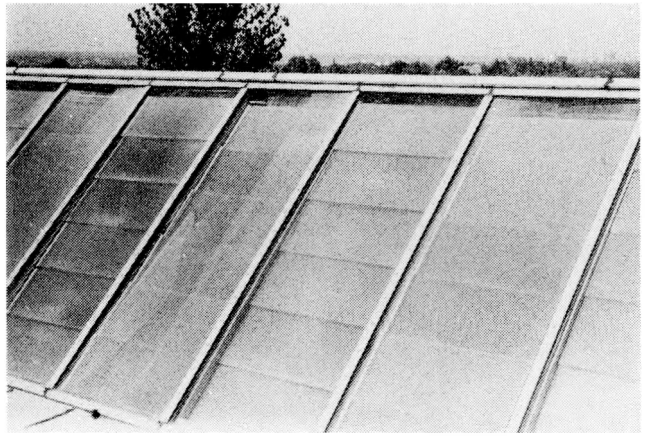


Fig. 4 — Examples of Lower Cover Plate Damage in Hot Panels

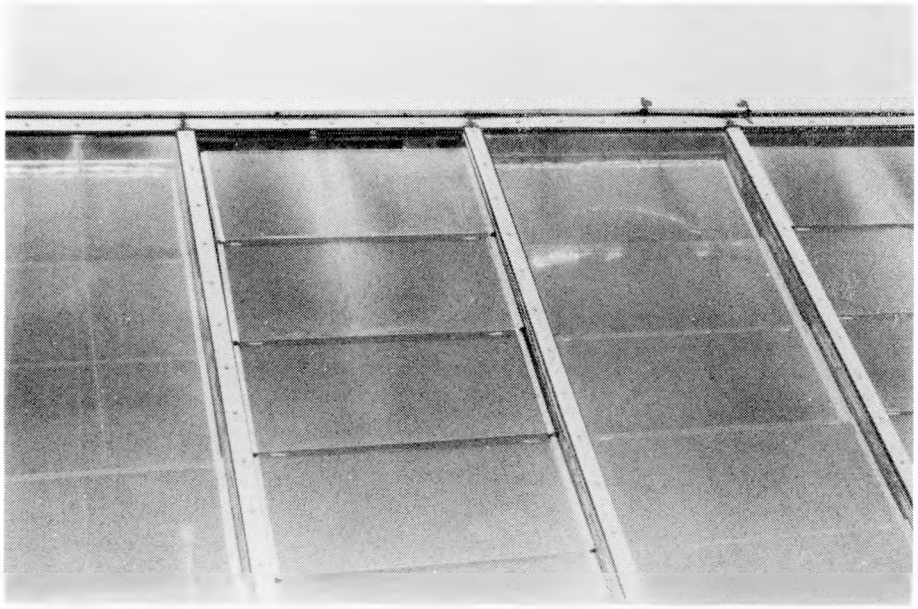


Fig. 5 — Examples of Absorber Plate Staining

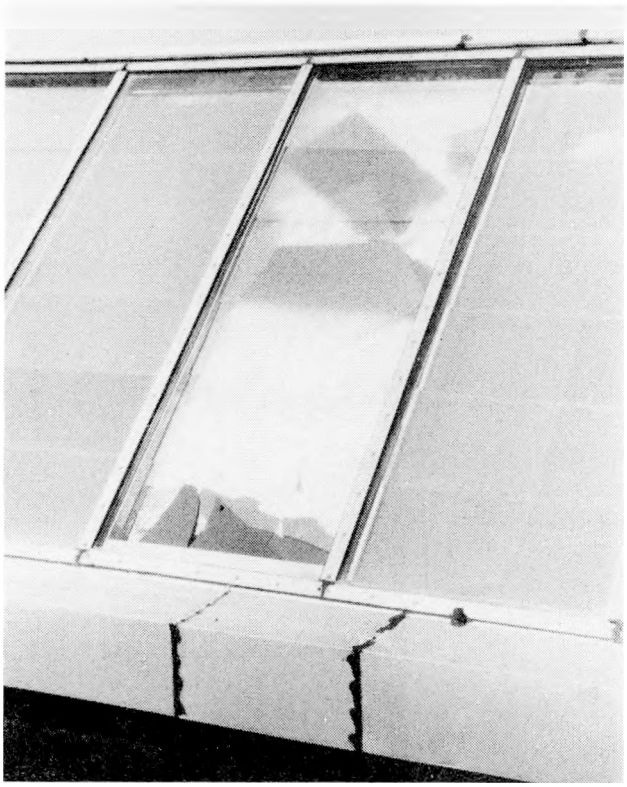


Fig. 6 — Extreme Example of Absorber Plate Breakage Caused Primarily by Improper Mounting

52 081

SPACE HEATING WITH SOLAR AIR COLLECTORS

by

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Twenty months ago, at the first solar heating and cooling workshop in Washington, I suggested that air should not be overlooked as a heat collection and transfer medium. But I think only Karl Boër and I had anything to say about hot air systems. I am gratified to see that in this program, solar air heaters are well represented.

The electricity by which this room is being illuminated costs 6 cents a kilowatt hour. That is $17 per million B.t.u. Even with a heat pump having a mean annual coefficient of performance of about 2 (a C.O.P. of 3 can be obtained as a heat pump, but the supplementary resistance heating usually required reduces the annual average), the effective energy cost is $8 to $9 per million B.t.u. With an annual heating requirement of 100 million B.t.u. in a typical three bedroom house, electric heating costs of $800 to $1800 are experienced. With a solar system requiring an investment of $6000 to $8000, amortization in 20 years at 8 per cent interest results in an ownership cost of $600 to $800 a year. By saving three-fourths of the electricity normally required, the cost of the solar system can be well justified.

I would now like to show how a solar air collector and pebble bed storage unit fit into the heating system for a building. Figure 1 shows that when solar heat is being stored for later use, the collector supplies hot air through a blower, a finned coil heat exchanger (if service hot water

is also being solar heated), an automatic damper, to a pebble bed heat storage unit. Air returns from the pebble bed to the collector for reheating.

Whenever the building requires heat (Figure 2), a damper changes its position, and the solar heated air passes through an auxiliary heater of some type, to the rooms, and back to the collector.

In the third mode, as shown in Figure 3, heat is supplied to the rooms when the sun isn't shining. Another damper changes its position so that the blower moves cool air from the rooms through the pebble bed (in a direction opposite to that in the storing cycle) and the auxiliary heater, to the rooms. In both modes of heating the building, air temperature is "boosted" by the auxiliary if (and only if), it is too low to meet the heating demand. These three air circuits require only one blower, two automatic dampers, and a simple air moving and control system.

A minor alteration in this system makes it suitable for moderate cooling in regions where there are substantial differences in atmospheric temperature between day and night. Figure 4 shows night air being drawn from outdoors by the blower through an evaporative cooler and into the storage bed, where the pebbles are cooled nearly to the wet bulb temperature; the warmed air is discharged to the surroundings through a vent. In daytime operation (Figure 5), outdoor air or recirculated house air is cooled by passage through the chilled pebbles and distributed to the rooms. In a dry climate such as in the western part of the United States, eight to twelve ton-hours of cooling can be obtained from a pebble bed designed to carry a typical residential heating load.

Turning now from the complete system to the subject of the collector, let us examine heat collection efficiency. Although not widely realized,

an air collector has an efficiency approximately equal to that of a liquid collector. This conclusion can be drawn from Figure 6, in which experimental data on the performance of an air collector are shown. Collector efficiency, defined as the useful heat recovered divided by the total energy falling on the collector surface, is plotted against air flow rate through the collector. Also depicted are delivered air temperatures corresponding to those efficiencies and flow rates, at conditions of 70 degrees ambient and 70 degrees entrance temperature to the collector, and a solar radiation level of 290 B.t.u. per hour per square foot (about .9 kilowatt per square meter).

The solar air heater involved in this experiment and analysis comprises two glass covers, a black metal absorbing surface, an air space, and a layer of insulation. Air is passed through the space between the black absorber plate and the insulation. Theoretical analysis of the heat transfer characteristics of this design yields values of F' of 0.83 and F_R of 0.70 at an air flow rate of 2 c.f.m. per square foot, in the equation,

$$q_u = A_c F_R \left[S - U_L (T_{in} - T_{amb}) \right]$$

where

q_u = useful heat recovery, Btu/hr

A_c = collector surface area, ft^2

F_R = heat recovery factor, dimensionless

S = absorbed solar radiation, Btu/hr, ft^2

U_L = overall heat loss coefficient, Btu/hr, ft^2, °F difference between absorber plate and ambient

T_{in} = inlet air temperature, °F

T_{amb} = ambient air temperature, °F

This value of the factor F_R means that the collector has an efficiency 70 per cent of what it would have if the absorber plate were at the same

temperature as the entering air. Use of this equation (with appropriate values of F_R at air rates other than 2 c.f.m./ square foot) results in the theoretical efficiencies shown by the dashed curve.

At a practical air rate of 2 c.f.m. per square foot of collector (corresponding to a pressure drop of about two-tenths of an inch of water through a 12 foot length), exit air temperature is seen to be about 160 degrees F at a heat recovery efficiency of about 50 per cent. These are typical values for a water heating collector as well as this air heater. In the range of 1 to 5 c.f.m., efficiencies vary from 40 to 60 per cent as exit air temperatures range from about 180 degrees down to 120 degrees. Differences between experimental results and theoretical analyses are being investigated.

The practical utilization of solar heating is favored by a system which can be applied to numerous types of buildings, in a wide range of climates, under conditions involving minimum maintenance and maximum service life. A solar air system can meet these requirements. There are no problems with antifreeze mixtures, heat exchangers, corrosion of collectors and storage tanks, and damage from leaking liquids. If air conditioning requirements are minimal, a simple type of day-night exchange cooling can be provided by use of the pebble bed storage unit.

An important influence on the performance of a solar air collector is exerted by the heat storage unit. A pebble bed is much more effective than a liquid or a phase change material because of the temperature stratification obtainable and the resulting improvement in collector efficiency. Hot air can always be obtained from the pebble bed if there is any heat in storage at all. Nine-tenths of the storage volume can be at 70 degrees Farenheit, one-tenth at 150 degrees, and hot air can be delivered nearly at the 150 degree temperature. It is a remarkably efficient, low-cost multi-purpose

device in which heat is transferred from collector to storage, from storage to the load, in which a large quantity of energy can be stored until needed.

Although a pebble bed has three times the volume of a water tank of equal heat capacity, the container is cheaper, common screened gravel is widely available at low cost, and basement space for a typical house unit has a value of only $300.

Commercial development plans involve investigation of several modified collector designs, which are expected to have higher efficiency and lower cost. Although efficiency is satisfactory at present levels, cost reduction is essential. Air collectors can soon be marketed at $5 to $6 per square foot; with materials in the vicinity of $2 per square foot, collector prices near $4 should be possible in the near future.

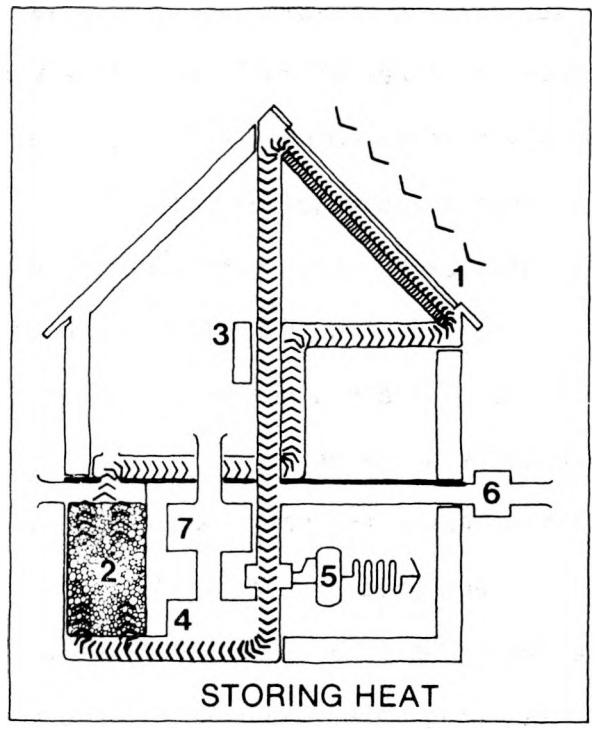


Fig. 1 — Storing Heat

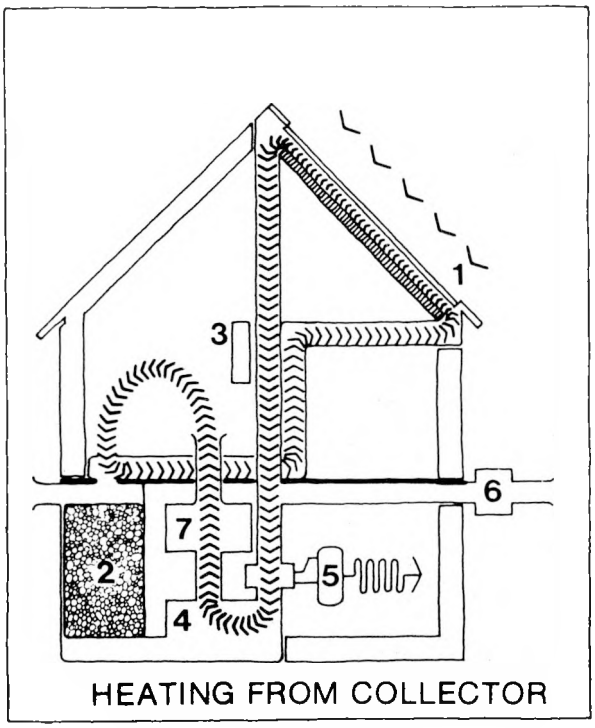


Fig. 2 – Heating from Collector

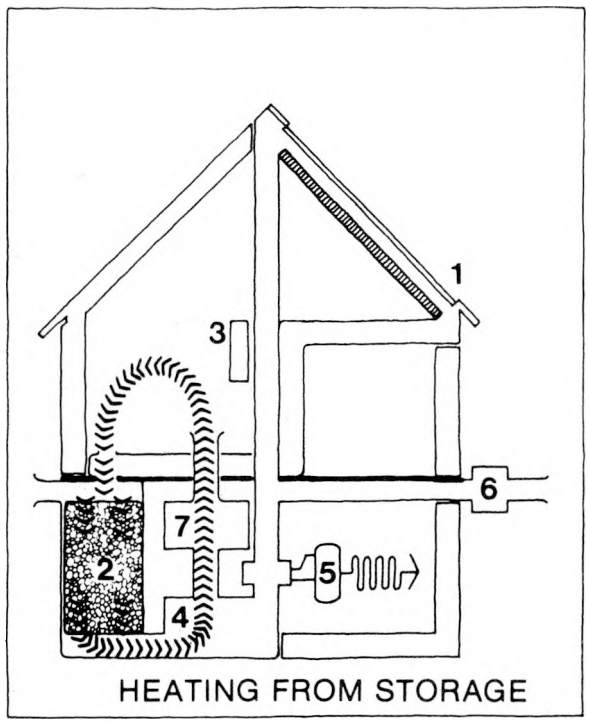


Fig. 3 – Heating from Storage

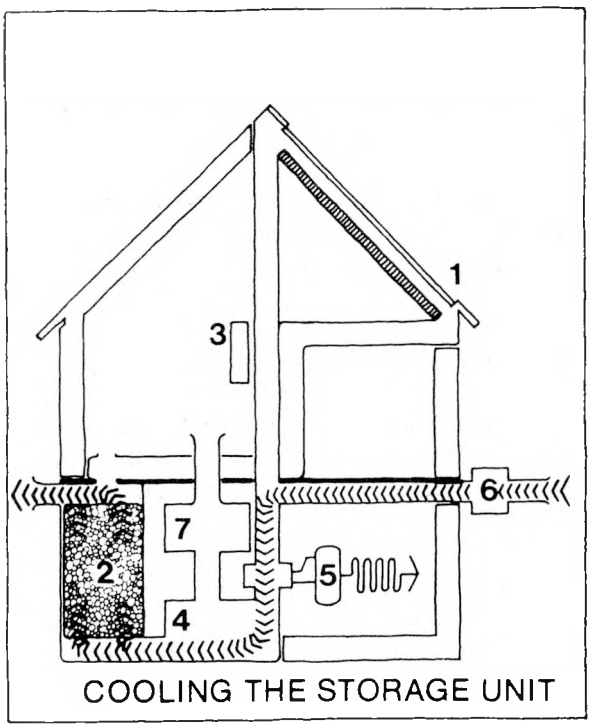


Fig. 4 – Cooling the Storage Unit

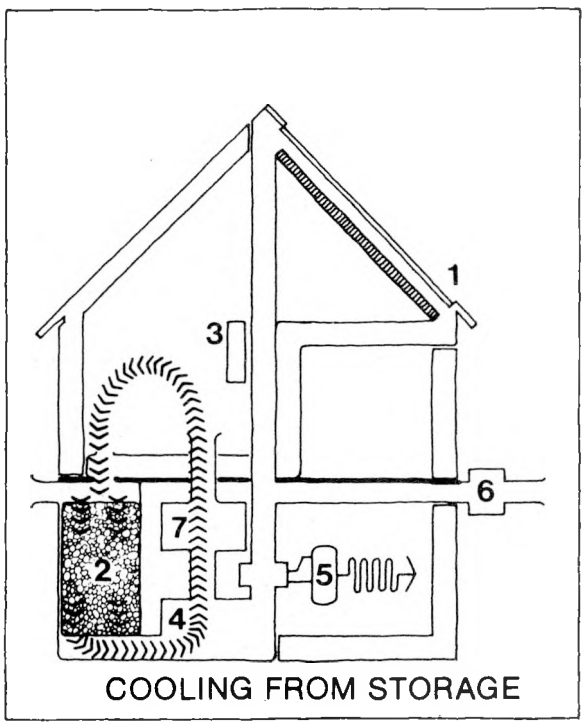


Fig. 5 – Cooling from Storage

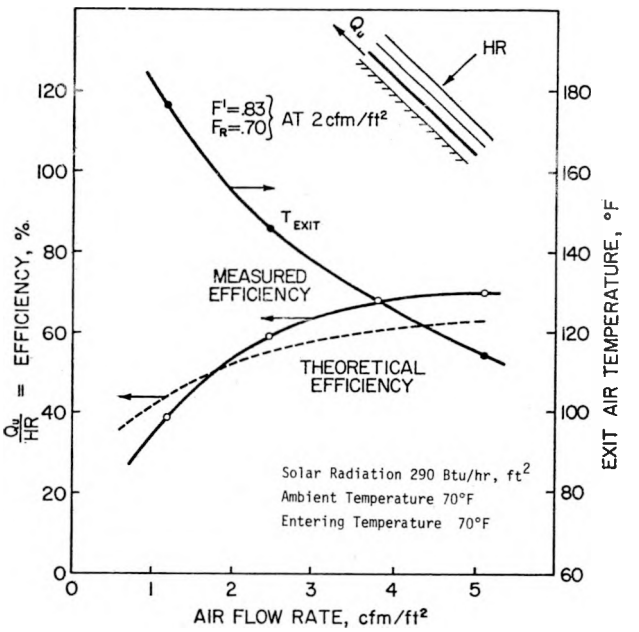


Fig. 6 – Performance of Solar Air Heater with High Solar Radiation

DISCUSSION

Question (Benicio I. Dussan V, Philadelphia, Pa.): You stated that air systems do not require a heat exchanger, yet you said that the pebble bed is a virtual necessity. Can you comment on that, please?

Answer (George O. G. Lof, Colorado State University): In the normal sense of the words "heat exchanger," you do not have to have one in the system, although the pebble bed, of course, is one. The air transfers its heat to the pebbles, and when you are using the pebble bed to heat the building the heat is transferred from the pebbles to the air that is circulating through the building.

Question (Mr. Dussan and Carleton Granbery, Architect): Is condensation a problem when using rocks for cooling?

Answer: The Australians have used what they call the "RBR System," which is short-cycle cooling using adiabatically cooled air to chill the pebbles and then using the cold pebbles to chill the air going into the building. They have not reported any problem with mold, or any other difficulties with the pebble bed. Therefore, we do not think we are going to either.

Comment (Robert W. Annis, Annis Electronics): I have just completed operating my home by methods you described, less any storage and collectors as such, for both heating and cooling over the past 7 months. The system failed for about 2 days during the summer, after a 2-week hot spell. It failed to produce warmth only 1 day in November, after continuously decreasing temperatures for over a month. There was no heating or cooling added during the period.

52,082

SOLAR COLLECTORS OF SOLAR ONE

by

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The "Solar One" University of Delaware's solar house-laboratory is located in Newark, Delaware (39° 42' North latitude).

Particulars of the house as a solar system were given in (1). For the purposes of this presentation, we would like to emphasize that the system operates with air, converts solar energy into electricity and thermal energy simultaneously, and uses a salt hydrate type phase change heat storage.

The solar collector development program of the house is geared to satisfy the requirements for an efficient CdS/Cu_2S solar cell operation and the melting of the salt hydrates in its main storage bin. The solar cells have higher efficiency and longer life expectancy at lower temperatures. A panel temperature of 65°C is acceptable. On the other hand, to melt the phase change storage materials, the discharge air temperature from the collectors should be about 8 to 11°C above the melting temperature of 49°C.

Coupled to these requirements is the additional condition that the pressure drop across the solar collectors should remain low for economic fan operation in the air circuit.

Within these guidelines, certain collector plate designs are adopted. This presentation gives some detail of the initial research findings on two particular solar collector duct designs.

The collectors on which research is conducted are labelled 17A* and 21-22 pair. The latter pair are two similar collectors connected in series with an interconnecting duct (Fig. 1). The former is the bottom collector of two dissimilar collectors in series located one pair apart from the 21-22 pair in the mid-region of the 45° roof.

The details of the collectors 17A and 21-22 pair plates and flow passage are shown in Fig. 2. Structure of the collector box and insulation is shown in Fig. 1. A second glazing is formed by the 12.5 mm thick Lucite AR** coated plexiglas sky-light of the roof and is separated by a 2.5 cm thick Butyl Rubber frame from the top glass cover of the collector box (Fig. 2).

The U-form fins of collector plate 17A are made of aluminum and are vacuum brazed to the aluminum collector plate. The 21-22 pair has straight fins of galvanized iron and these are soldered to the galvanized iron plate.

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* The collector plate is courtesy of Harrison Radiator Co. of General Motors.
**Trade name by DuPont Co.

The distinguishing feature of these two plates is the interruption of the flow by the non-continuous, staggered fins. For 17A, the interruptions are much more frequent than for the 21-22 pair. It was expected that the heat transfer enhancement in 17A will be much higher than in the 21-22 pair, however at the expense of an increased pressure drop through the air duct of collector 17A. The purpose of this study is to compare the heat transfer and pressure drop in such extensively finned solar collector ducts with those of non-finned smooth ducts of similar dimensions. Additionally, cross correlations of the two finned ducts are sought.

The collectors are instrumented typically as shown in Fig. 3. Collectors 21 and 22 are subjected to roof tests alone. Most of the tests on collector 17A are conducted in an indoor test facility with electric heating to substitute for solar insolation. Whenever roof tests are conducted, the conventional procedures are followed, such as choice of clear sunny days, attainment of the pseudo-steady state, minimum 15 minute testing time. In analyzing the heat transfer and the pressure drop, two different definitions for the hydraulic diameter (d_h) are utilized. In the case of collector 17A, the overall duct entrance dimensions are used to define it. In the case of collectors 21-22, the flow cell formed by two neighboring fins, the plate and the adiabatic back wall is used. Later, in comparing the collectors 21-22 pair and the 17A, however, the overall duct dimensions are utilized for both cases, so that the comparisons could be put on equal footing, In such cases, the pertinent parameters like Nu number and the friction coefficients "f" are identified with subscript "d".

Tests are run over a range of flow rates to cover the transition region and the lower region of the turbulent flow regime. The transition region is assumed to extend between $2000 < Re < 6000$ where Re is formed with the mean velocity (U_m) in the ducts and the pertinent hydraulic diameter.

Data and Results:

Figure 4 shows the pressure drop for collector 17A along the normalized axial distance from the abrupt entrance at Re = 14000. Following the entrance drop, ΔP_o, the flow attained full development after about 21 d_h at this particular Re number. The "f" value (see Fig. 10) is computed, using the (dp/dx) following hydrodynamic development.

In Fig. 5 the typical axial plate and bulk air temperature profiles are shown for collector 17A. It appears that thermal development is achieved within 6-8 d_h for the given flow rates. At the exit, the plate to bulk air temperature difference was in the order of 4°C for a 100 cfm flow rate. With a maximum plate temperature of 44°C and an outside air temperature of 18°C, a conventional efficiency of 74% was found. A similar set of curves shown in Fig. 5 is for a very low flow rate in order to increase the plate temperature, hence to increase the heat losses. Thus, a lower value could be found for the collector performance. The conventional collector efficiency was 49% where the maximum plate temperature reached about 80°C at an outside air temperature of 7°C. Even at such low air flow rates*, the plate to bulk air temperature difference increased only to 6°C.

In Fig. 6 various axial temperature data are shown for two Re numbers for collector 21. Again, the plate and bulk air temperatures indicate a thermal development, however, farther downstream from the entrance of the duct compared to collector 17A.

* For normal house operation, the air flow rate is 250 cfm.

In Fig. 7 the data for a wider air flow range are shown for collector 21. Here both the axial distance and the plate bulk air temperatures are plotted in non-dimensional forms. The non-dimensional temperature

$$\theta = \frac{T - T_{in}}{Id_h/k}$$

comprises a convenient grouping of the three system variables: the inlet air temperature, T_{in}; total insolation, I; and the hydraulic diameter for the duct, d_h (k is the thermal conductivity of air). In this reduced form, a good visual appreciation of the plate-bulk air temperature variations is obtained for different flow rates characterized by varying Re numbers.

The local plate-bulk air differences are subsequently utilized to form a heat transfer coefficient which in turn is used to define the local numbers (Nu_x). The results are shown in Fig. 8. The rise near the duct exit in the Nu_x vs. x/d_h plots for Re numbers lower than 3800 is attributed to the increasing effect of the assisting free convection in the duct (2). However, this matter requires further work for rigorous demonstration.

If it is assumed that the Nu numbers computed for the last measurement station (at $x/d_h \simeq 44$) are the fully developed values for Nu, then Fig. 9 can be plotted to show correlation of Nu with Re. For collector 17A the triangles are the on-the-roof test results, whereas circles are the indoor test results. The solid lines through the test points are the faired lines. For asymmetrically heated ducts for all aspect ratios, the literature reports a correlation of the form (3,4):

$$Nu_{fd} = 0.018\ Re^{0.8}\ Pr^{0.4}, \qquad \text{(for air Pr = 0.70)}$$

This is indicated as the lowest line in Fig. 9 (Nu_{fd} is the fully developed Nusselt number).

At a given Re, the increase in Nu, compared to a smooth asymmetically heated duct of same overall dimensions, is by about a factor of 33 for collector 17A and by a factor of 3.3 for collectors 21-22 pair (Fig. 9), indicating a substantial increase in heat transfer.

At the same time, an increase of the friction factor, compared to a similar smooth duct which obeys the Blasius law, is approximately 20 folds for 17A and 3 folds for collector pair 21-22 (Fig. 10). The latter factor reduces to 1.7 if the interconnect pressure loss between the two collectors is discounted. In Fig. 10 f_{app} includes these losses and therefore appears to be high. One interesting aspect of Fig. 10 is the apparent independence of f from Re for 17A, while such an independence is not evident in f_{app} for the 21-22 pair. No explanations will be offered at this point until more research is conducted on such ducts with frequent axial interruptions in the fins.

Neither of these collector ducts have met all the design criteria cited in the beginning of this presentation. However, the results have shown that proper finning with interrupted fins can markedly increase the heat transfer, hence reducing the temperature drop between collector plate and air, while keeping the pressure drop within bounds for the flow circuit (currently 1.7" for the house system). More research is planned to study the hydrodynamic and thermal characteristics of such asymmetically heated rough ducts with different fin configuration for a range of Re as frequently encountered in solar collector flows.

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   Part III: Kuzay, T. M., Malik, M.A.S., Ridenour, S. M., Telkes, M. and Böer, K. W., "Insolation and Total System Performance."

   Part IV: Kuzay, T. M., Malik, M.A.S., Ridenour, S. M., and Böer, K. W., "Experimentation with Solar Collectors."

2. McComas, S. T., and E.R.G. Eckert, "Combined Free and Forced Convection in a Horizontal Circular Tube," J. of Heat Transfer, Transactions ASME, C, 88: 2 (1966), pp. 147-153.

3. Sparrow, E. M., Lloyd, J. R., and Hixon, C. W., "Experiments on Turbulent Heat Transfer in an Asymmetrically Heated Rectangular Duct," J. Heat Transfer, Transactions ASME, 88: 170 (1966).

4. Tan, H. M., and Charters, W.W.S., "An Experimental Investigation of Forced Convective Heat Transfer for Fully Developed Turbulent Flow in a Rectangular Duct with Asymmetric Heating," Solar Energy, Vol. 13, 121-125 (1970).

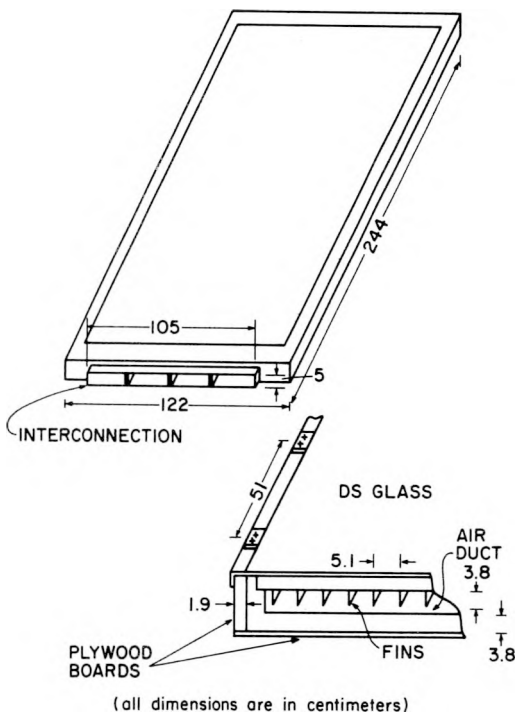


Fig. 1 – Overall View of the Typical Test Collector

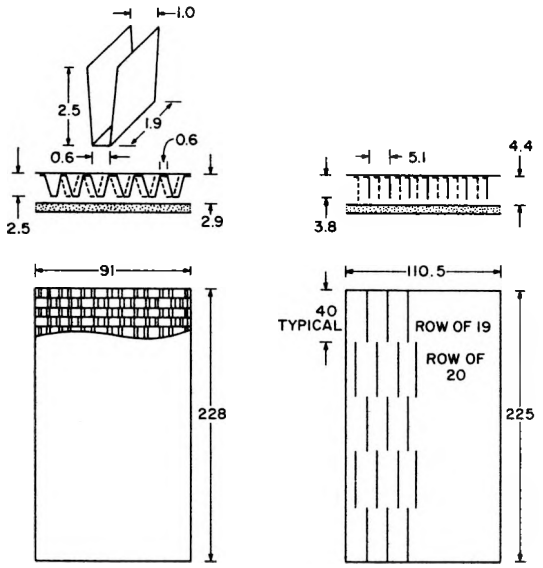


Fig. 2 – Collector Plate Details: 17A and 21-22

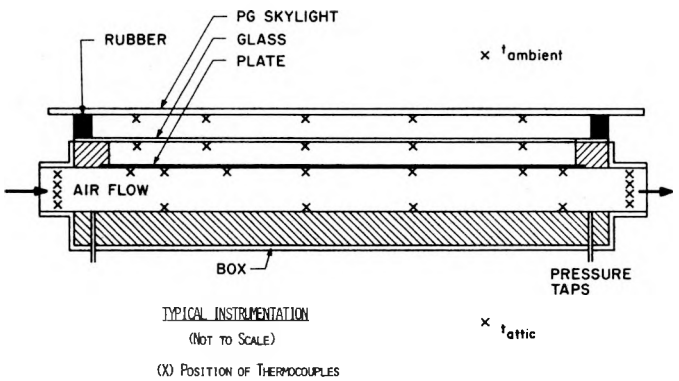


Fig. 3 – Representative Collector Instrumentation for Testing

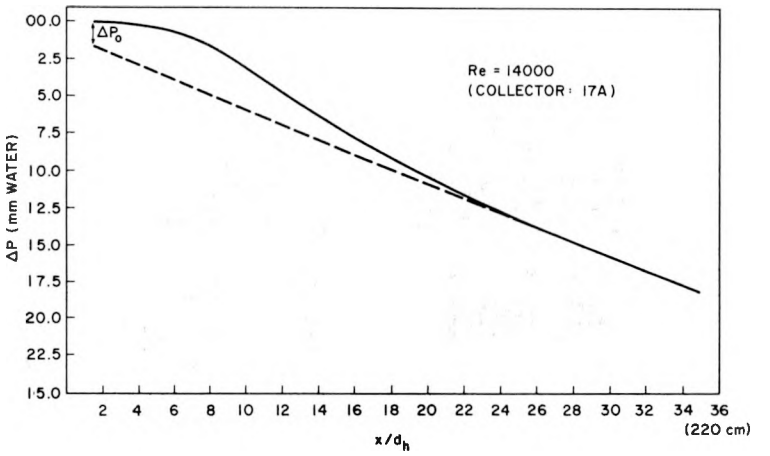


Fig. 4 – Pressure Drop vs. Duct Length for Collector 17A

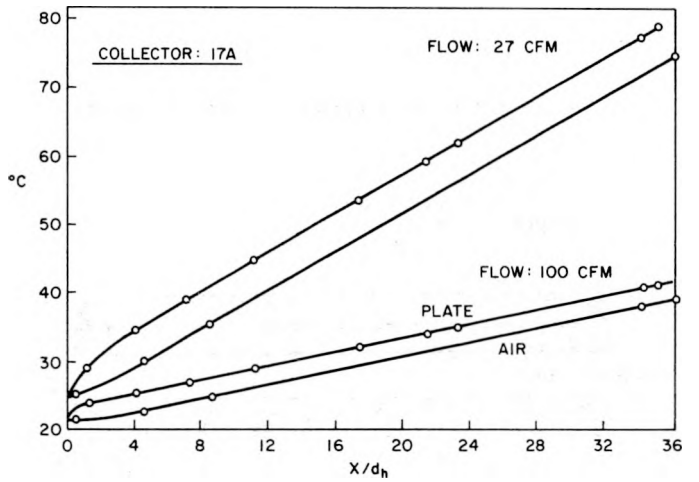


Fig. 5 – 17A: Plate Bulk Air Temperatures: Axial Variation

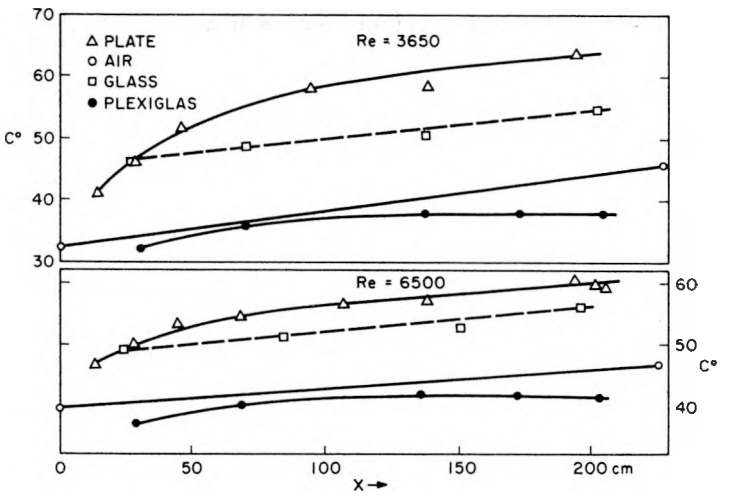


Fig. 6 – Axial Temperature Profiles for Collector 21

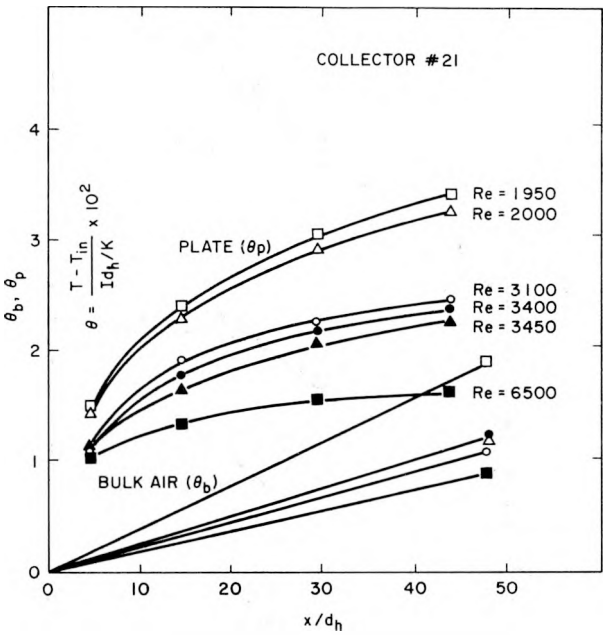


Fig. 7 – Reduced Axial Temperature Variations for Plate and Bulk Air for Collector 21

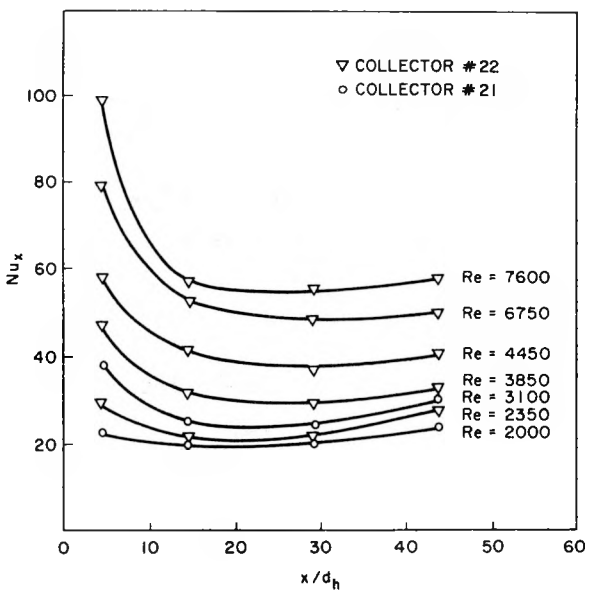


Fig. 8 – Local Nu_x vs. Axial Distance for Collectors 21 and 22

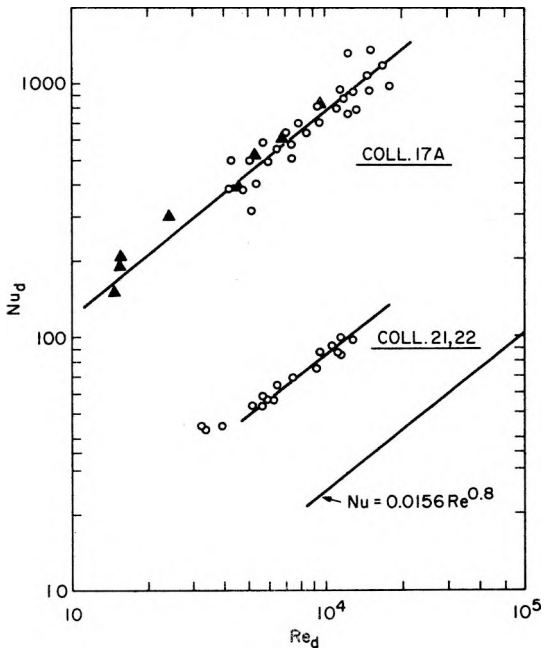


Fig. 9 – Comparison of Fully Developed Nu-Re Correlations for Collector 17A and 21-22 Pair with an Asymmetrically Heated Smooth Duct

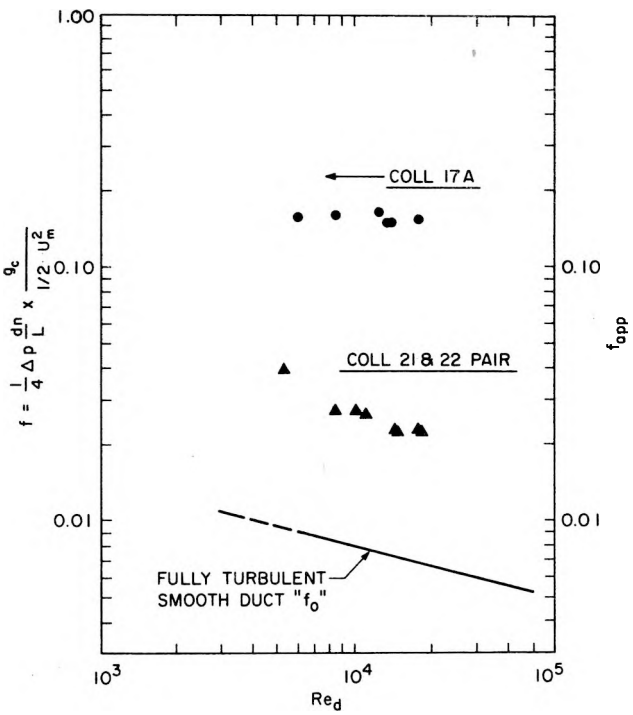


Fig. 10 – Comparison of Friction Factors for Collectors 17A and 21-22 Pair with a Smooth Duct Obeying Blasius Law

DISCUSSION

Question (Herman G. Barkmann, Barkmann Engineering): Could you compare the two upset plate absorbers to a plain flat absorber?

Answer (Tuncer M. Kuzay, University of Delaware): Figures 9 and 10 of the presentation show the results of comparison in heat transfer and friction factor. Bottom lines on both figures are the results for a duct with plain flat plate absorber. However, in the case of collectors 21 and 22, an apparent friction factor (f_{app}) is used, which is read off the right-side ordinate. The distinction between f and f_{app} is that f_{app} includes all the pressure losses after inlet and before outlet of pair 21 and 22 combined, including the interconnect losses which would not be included ordinarily. For this reason, a higher friction factor is computed. Also, it should be noted that f as read off the left-hand ordinate for collector 17A is based on fully developed dp/dx in the collector duct. A similar procedure could not be applied to the 21 and 22 pair because the overall pressure drop was small and, therefore, with our existing instrument capability, large inaccuracy would result from trying to read small pressure differences along the duct.

Question (Matthew L. Cohen, Rensselaer Polytechnic Institute): How have you solved the breakdown problem of the salt over repeated cycles through its transition temperature? How do you store the salt hydrate, and which compound do you use?

Answer: The questions are best answered by referring the reader to reference [1] of the presentation and also to the following: Telkes, Maria, "Solar Energy Storage," *ASHRAE Journal,* Sept. 1974, pp. 38-44.

Question (Donald R. Scott, Columbia Gas System): What is the projected mass-produced cost of your air collector—the factory f.o.b. price?

Answer: We are in a developmental program. Therefore, optimization work for the collector plate has not yet been finalized. We will be able to project a cost figure on completion of this work.

Question (Richmond A. Gooden, United Aircraft Products, Inc.): Please elaborate on details of fin material thickness and method of attachment to the collector plate. What size were the sections of construction?

Answer: Here are the particulars:

Collector 17A	Collectors 21 and 22
Fin material: Aluminum 0.040 in.	Galvanized iron 0.020 in. thick
Plate material: Aluminum 0.040 in.	Galvanized iron 0.020 in. thick
Bonding method: Vacuum brazed	Soldered
Subpanel size: 2 ft x 4 ft nominal	Full 4 ft x 8 ft size

Question (Gary C. Vliet, University of Texas at Austin): In one of your earlier slides you show that both the plate and fluid temperatures increase essentially linearly with x/d_h, which would indicate that the "local" efficiency does not vary with collector temperature. Could you please comment on this, as it appears contrary to what one would expect.

Answer: Linear variation of the collector-plate temperature and the bulk temperature of the fluid (air) as a function of (x/d_h) is an indication of full thermal and hydrodynamic development in the asymmetrically heated collector duct under uniform heat flux. Under this condition, the local heat transfer coefficient (h), or equivalently the Nusselt Number (Nu) reach a steady-state value. A similar phenomenon would be found in any similar duct flow, unless, let us say, a very strong radiation mechanism or else a strong free convection mode modifies it. Except in very low Reynolds Number, no such effects were noticed in our studies, subject to the limitations of our current instrumentation and measurement capabilities.

Comment (R. Allen Moran, Lehigh University): An examination of the materials presented in this session suggests that the bulk of the work that has been done with flat plate solar collectors has concentrated on roof-mounted collectors and, thus, has limited the study of collector design effectiveness to buildings of a configuration in which the roof area is large relative to building volume. For a variety of economic reasons (the most obvious of which is the cost of land), there may be instances in which the roof surface is a dimension one would wish to minimize. An obvious example of this situation is the case of high-rise buildings in urban areas.

If one abstracts for the moment from the problems of siting such buildings relative to their neighbors, studies have shown that for much of the United States wall-mounted vertical flat plate collectors are close in efficiency to their roof-mounted counterparts. In view of the fact that Solar One has both roof-mounted (types 21 and 22) and wall-mounted (type 17) collectors, it would be interesting to know if the relative efficiency of energy collection and costs of installation and maintenance for the two types of collector have been examined in detail. The value of such information might be considerable in its contribution toward the identification of economically viable uses of solar energy in HVAC systems in the important area of high-rise construction.

I would be very much interested in hearing from Dr. Kuzay concerning his reaction to my remarks, if he feels that the experience with Solar One sheds any light on the potential of wall-mounted collectors for use in high-rise buildings.

Response: Vertical and tilted south-oriented surfaces do have large differences in terms of the direct radiation they receive from the sun. However, for 40° north latitude, the difference is relatively small for the approximate period November 15 to January 15, when the tilt angle is greater than, let's say, 30°. For the rest of the year the difference becomes very large. When latitude, tilt, and orientation are collectively brought into the picture, the problem becomes more complicated to explain in a few words. We would suggest looking up one of the many references available on the subject.

In terms of efficiency of the collector, it could be the same in both wall and roof deployment. However, there will be many other economic factors to dictate a solution, depending on the application (heating alone, heating and/or cooling, etc.). Problems with high-rise structures in solar applications may merit a separate session in future solar energy meetings.

52,083

HEAT PIPES APPLIED TO FLAT PLATE SOLAR COLLECTORS

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The objective of this program (NSF Grant AER 74-09164) is to investigate the feasibility and merit of incorporating heat pipes into flat plate solar collectors. Heat pipes are passive heat transport devices of very high equivalent thermal conductance. Because of their high conductance, they appear to be well suited to transport the collected energy from the absorber to a liquid or air distribution system. The emphasis of this program is on the heat removal aspect of the collector. Other features of the collector such as surface coating, glazing, and insulation are assumed to be similar in technology to that employed in conventional collectors.

The basic components of a heat pipe are shown schematically in Figure 1. A small amount of liquid which is in equilibrium with its saturated vapor is sealed within a leak-tight envelope (usually a tube). Application of heat to one section of the envelope causes some evaporation of the liquid in this section. The excess vapor condenses at the unheated section (condenser) of the heat pipe. The condensate is pumped to the heated section (evaporator) by means of capillary forces in a wick, thus completing the cycle. Heat is transported by mass flow via the latent heat of evaporation. In some applications such as the present one, gravity can be utilized instead of capillary forces to return the condensate to the evaporator. Because the process of evaporation and condensation under constant pressure is basically isothermal, the heat pipe is capable of transporting thermal energy with very small temperature differences.

The potential advantages (along with some disadvantages) of heat pipe solar collectors are listed in Table I. Gravity assisted heat pipes are unidirectional conductors; that is, they behave as thermal diodes. If they are properly oriented, heat is transported only from the absorber surface to a collection manifold but never in the opposite direction. This feature is expected to reduce heat losses from shaded or defective sections. Also, by virtue of being sealed systems, corrosion can be minimized and a mechanical attachment to the manifold appears feasible.

Table II shows the program plan. Since its initiation in August 1974, the thermal performance of various heat pipe collector designs have been evaluated and compared to conventional collectors of similar design. The comparative evaluation was performed on the basis of the well known Collector Efficiency Factor (F'). A typical collector having a specified tube spacing, fin effectiveness, heat loss coefficient, and size was selected as the reference. Heat pipe solar collector configurations with similar F' factors and comparable efficiencies to those of the conventional reference collector are shown in Figures 2 through 6.

Figure 2 depicts the incorporation of heat pipes into the absorber surface. The heat pipes could be fabricated as individual tubes and then brazed to the absorber surface, extruded tubes, and integral absorber segments, or could be fabricated as a part of "Roll Bond" panel. The interface between the heat pipe condenser and a liquid collection loop is shown in Figure 3. Optimization of this interface is of utmost importance in order to avoid excessive thermal impedances. The various mechanical interfacing arrangements shown in Figure 3 are of a clamp-on type. Thus, the collector may be completely prefabricated and field installed without using fluid connections. A typical installation is shown in Figure 4.

Heat pipe solar collectors are equally applicable to air heating systems. Referring to Figure 5, the heat pipes terminate in finned tube sections which are located inside an air duct. The air duct is part of the prefabricated collector and field installation requires only the joining of the duct sections. Figure 6 shows an air heating system in which finned convectors are attached to the condenser portion of the heat pipes. Installation simply requires mounting the collector panels to an air duct provided with appropriate openings and flanges.

The preceding examples of heat pipe solar collectors do not explicitly utilize the unique diode property of a gravity assisted heat pipe. As observed earlier, this unidirectional heat transport capability can reduce heat losses from inactive or defective collector sections. Moreover, special collector designs can be devised in which the diode feature increases the collector efficiency during periods of low insolation. Two examples of such designs are shown in Figures 7 and 8. The first design (Figure 7) utilizes small reflectors which are located at right angles to the collector surfaces. During normal incidence, the reflectors do not interfere with the sun's rays and the collector efficiency is identical to that of a conventional collector. During oblique incidence (other than noon), part of the absorber surface is shaded by the reflectors and part receives additional illumination via the reflectors. This results in increased efficiency during periods of oblique incidence. This increased efficiency is derived from the diode action of the heat pipe absorber. The illuminated portions of the surface contribute to the heat collection, whereas the shaded portions do not contribute to heat losses. The efficiencies for this and the Figure 8 design were calculated using typical collector and insolation parameters. The same parameters were applied to the heat pipe and the conventional reference collector.

Another design approach is shown in Figure 8. Here the collector surface is convoluted with individual segments forming an included angle of 90°. Again, the objective is to increase collection efficiency during periods of oblique incidence. At normal incidence, the efficiency is somewhat lower than that of a conventional flat plate collector. This is due to the increased area (increased by $\sqrt{2}$) which causes higher heat losses than those of an equivalent flat plate collector. However, during periods of oblique incidence, the illumination is concentrated on a smaller area. Because of the diode action of the heat pipes, thermal losses occur only from the illuminated sections and the efficiency of energy collection is substantially increased.

The above are only two examples illustrating the use of diode action of the heat pipes to spread out high efficiency energy collection over larger portions of the day. It can also be shown that, for the given set of collector and insolation parameters, the total rate of daily collection is increased by approximately 10%.

In summary, a heat pipe solar collector is applicable to liquid and air heating systems. It can be modularized for convenient mechanical attachment to a preinstalled heat collection loop. Its thermal effectiveness is approximately the same as that of an equivalent conventional collector. Through special designs, the diode action of the heat pipes can be utilized to increase daily collection rate and to flatten out the efficiency curve over a day to achieve higher efficiencies during early morning and late afternoon hours.

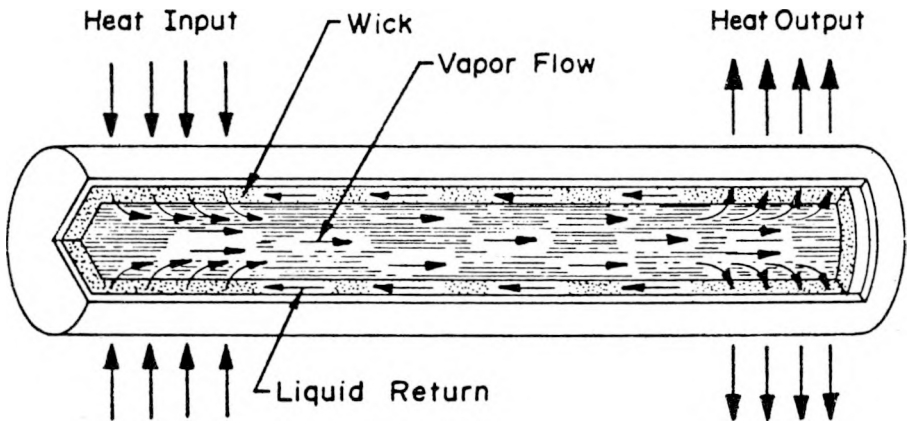


Fig. 1 — Elements of Heat Pipe

ADVANTAGES

- Heat Pipe Acts as Thermal Diode - Transports Heat From Absorber Surface to Transport Loop, but not in Reverse Direction
- Completely Sealed System - Corrosion is Minimized
- Heat Pipe Solar Collectors are Complete Modules - Can be Mechanically Attached to Transport Loop
- Freezing of Exposed Collector Surfaces Impossible - Need no Draining or Antifreeze
- Adaptable to Air and Liquid Heating Systems
- Lower Pumping or Blower Requirement that Conventional Collectors

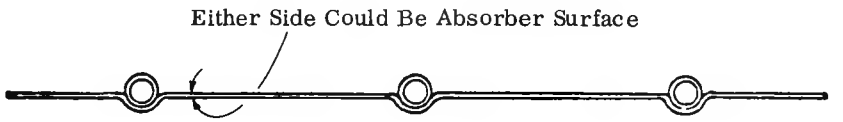
POTENTIAL DISADVANTAGES

- Heat Pipes May Add to Cost
- Additional Thermal Interfaces May Lower Effectiveness

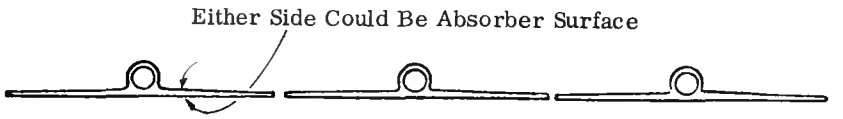
TABLE I: FEATURES OF HEAT PIPE SOLAR COLLECTOR

Task I	Configuration Studies: Module Geometry, Architectural Constraints, Construction Techniques, Thermal Terminal Configurations
Task II	Parametric Performance Studies: Math Models, Trade Offs, Baseline Design
Task III	Economic Analysis: Material plus Processing Cost
Task IV	System Integration Studies: Application of Heat Pipe Collector to Typical HVAC System
Task V	Submodule Fabrication and Testing: Laboratory Tests of Representative Section
Task VI	Full-Scale Module Fabrication and Testing: Tests with Solar Insolation

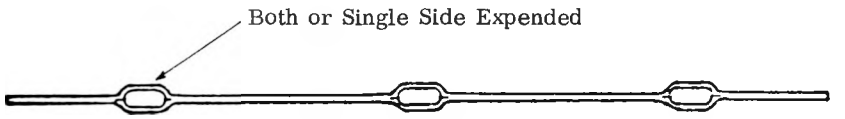
TABLE II: PROGRAM PLAN



A. Individual Heat Pipes Bonded to Absorber Plate in Preformed Grooves

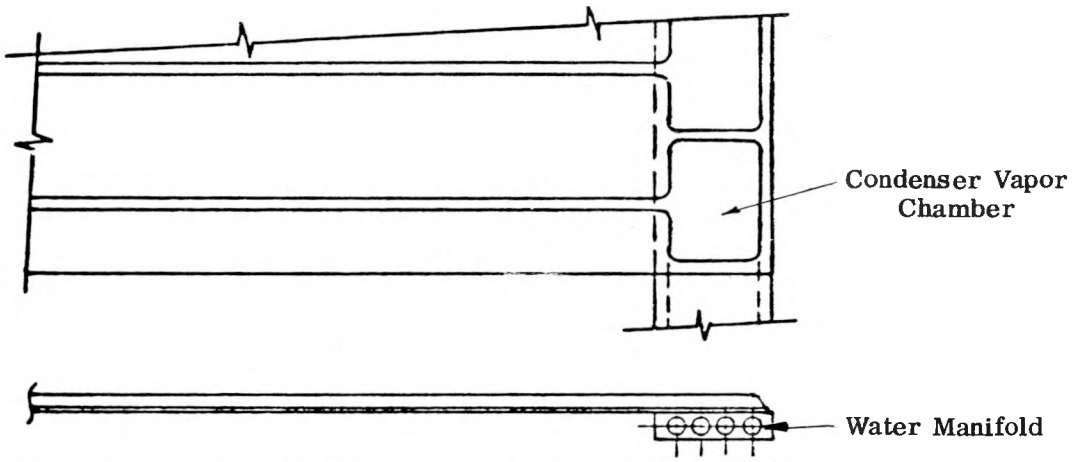


B. Individual Heat Pipes Extruded with Integral Absorber Fins

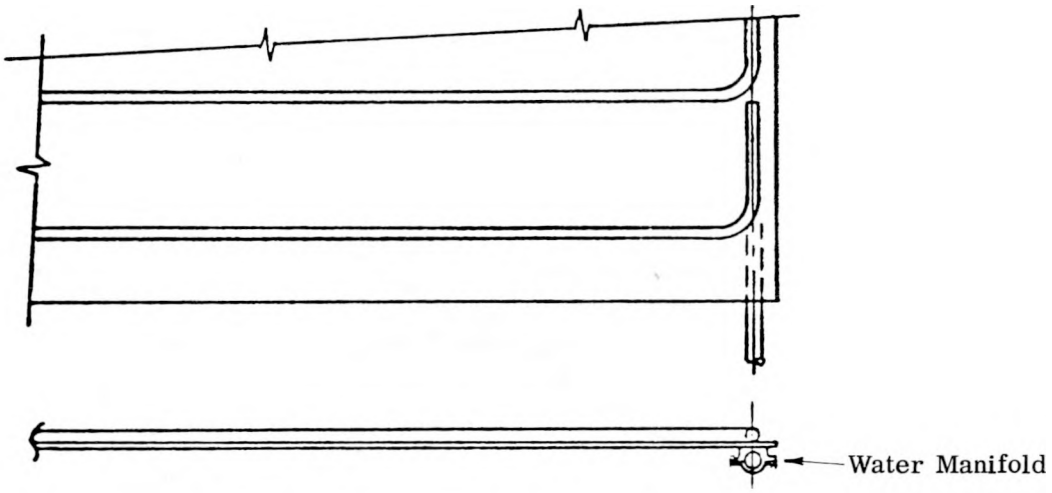


C. Absorber Plate with Integral Heat Pipes Formed in 2-Piece Bonded Plate

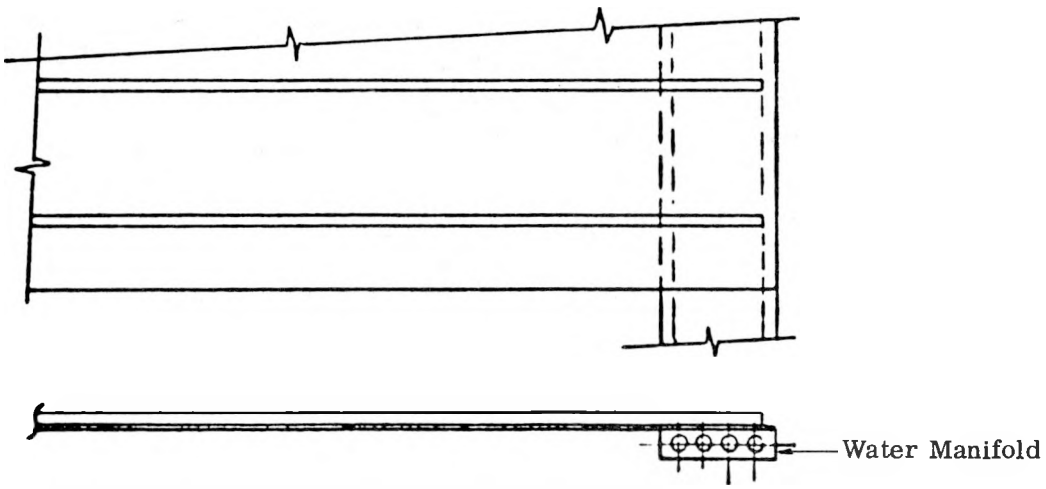
Fig. 2 – Incorporation of Heat Pipes into Absorber Plate



A. Condenser Vapor Chamber Formed in 2-Piece Bonded Plate



B. "L" Shaped Individual Heat Pipes Bonded to Absorber



C. Straight Individual Heat Pipes Bonded to Absorber

Fig. 3 — Typical Interfacing Between Heat Pipes and Liquid Manifold

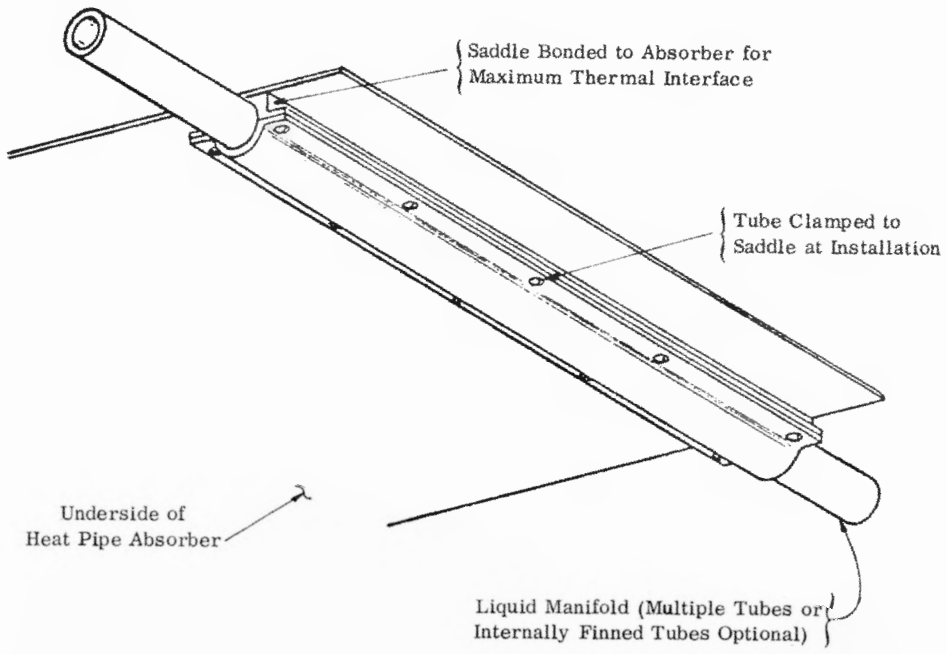


Fig. 4 – Mechanical Attachment of Heat Pipe Absorber to Liquid Manifold

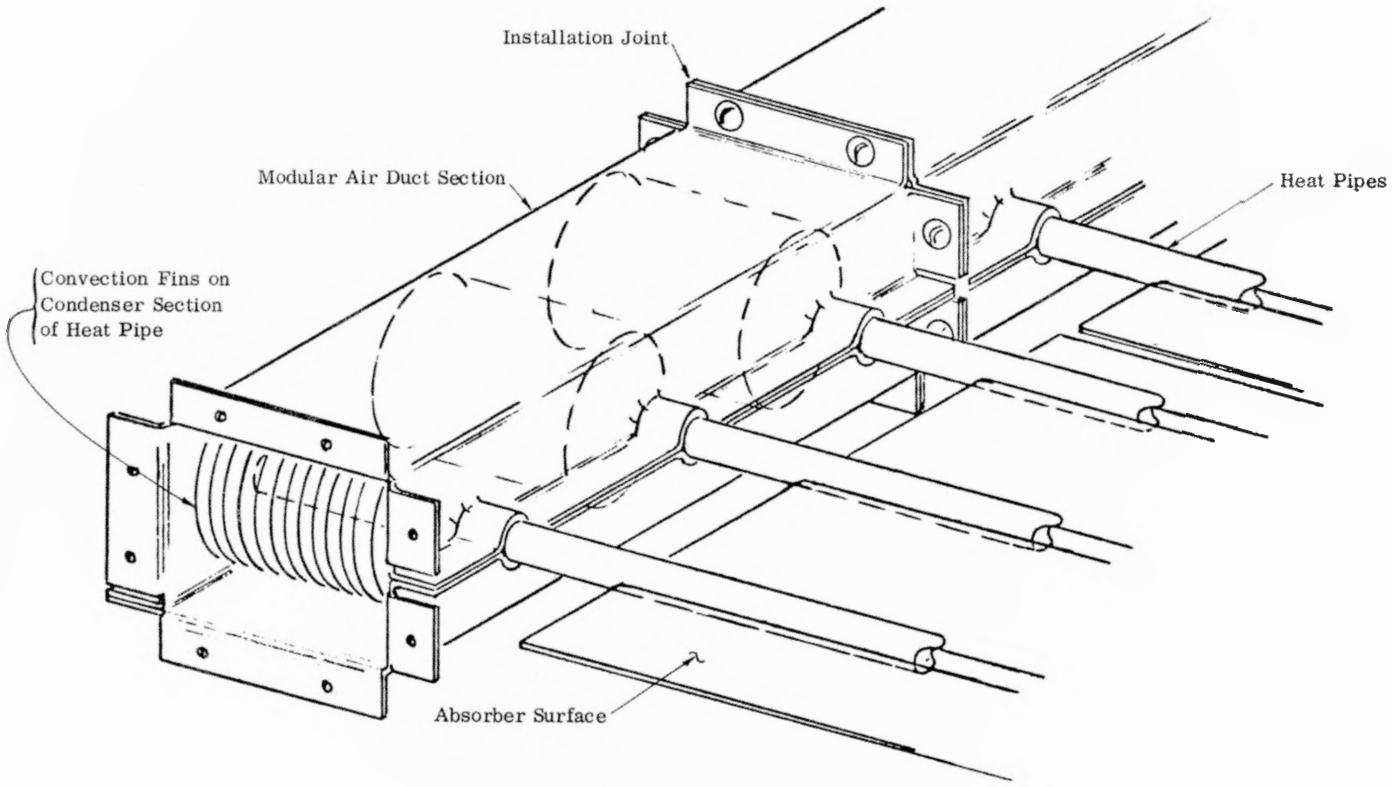


Fig. 5 – Heat Pipe Collector with Integral Air Duct Section

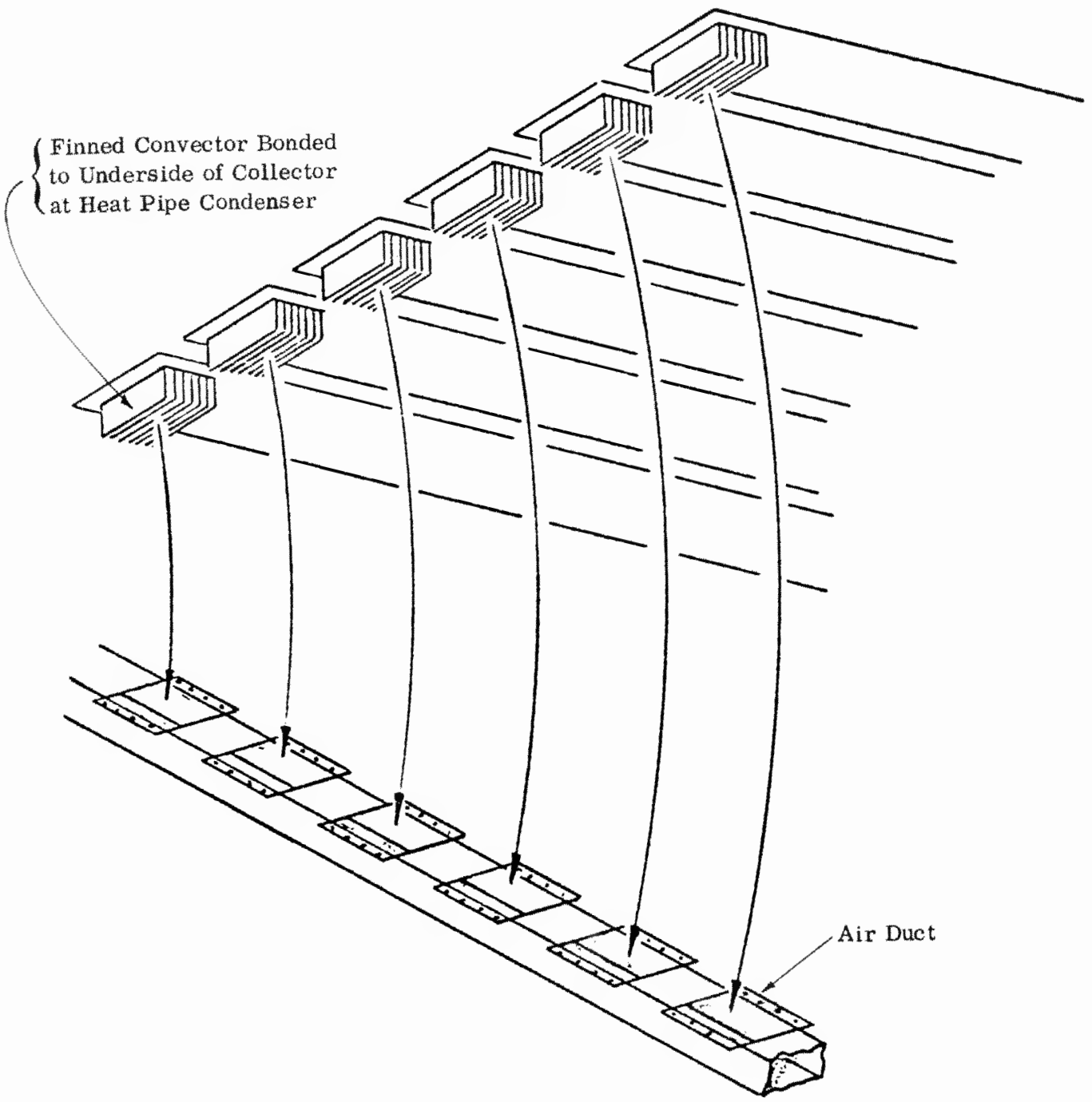
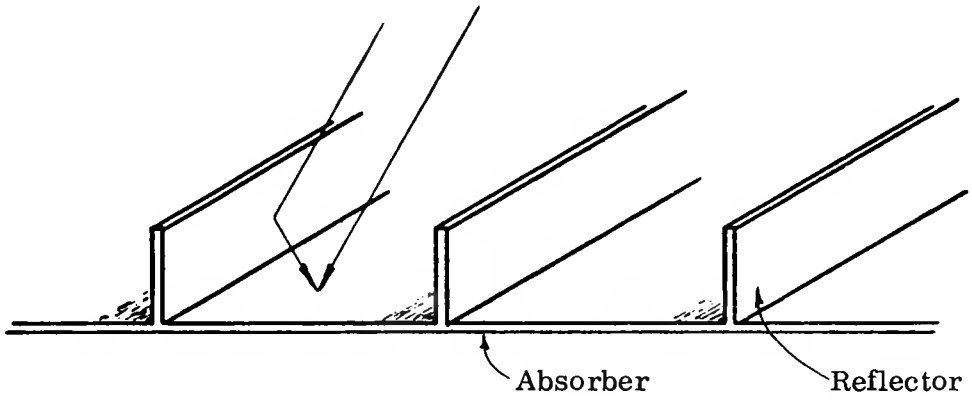
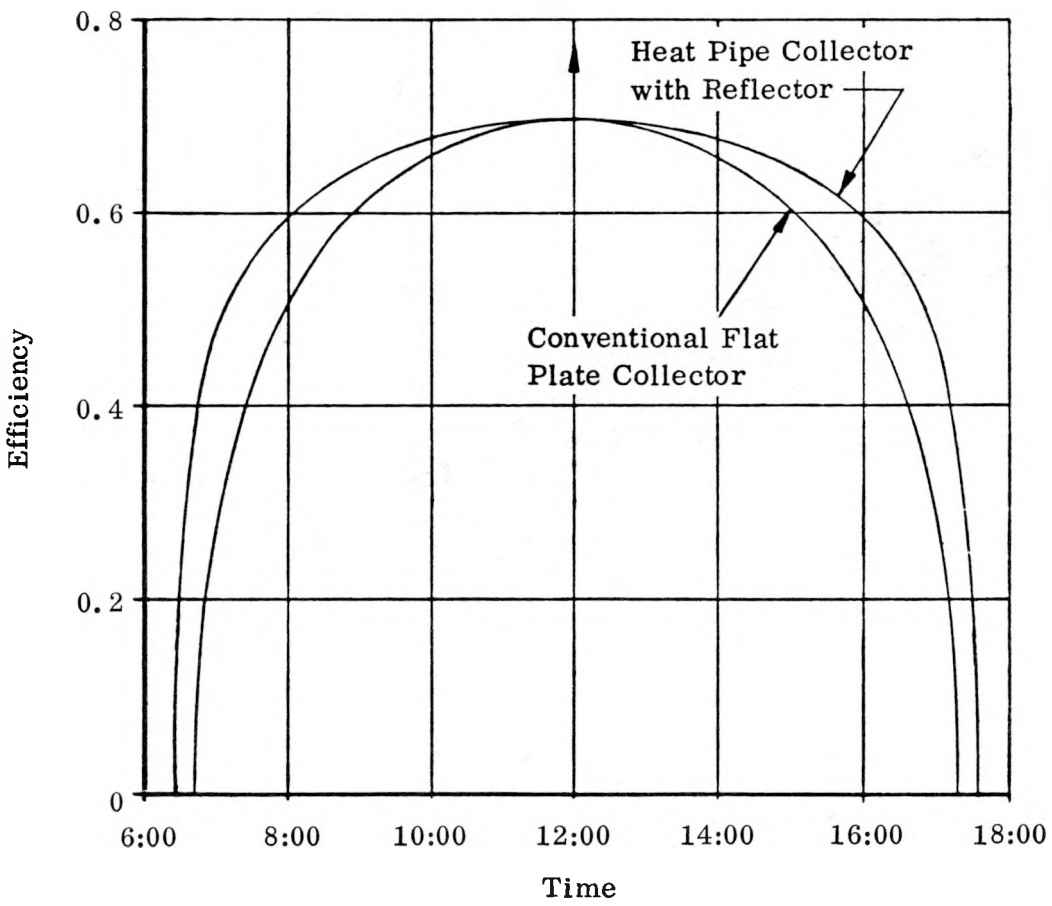


Fig. 6 → Heat Pipe Collector Attachment to Preinstalled Air Ducting

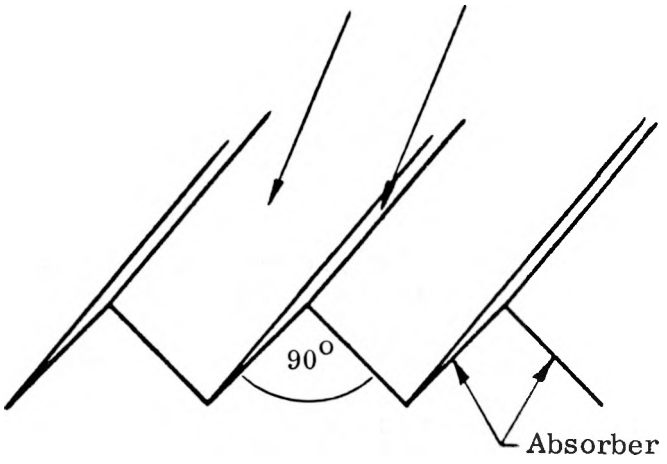


A. Geometry

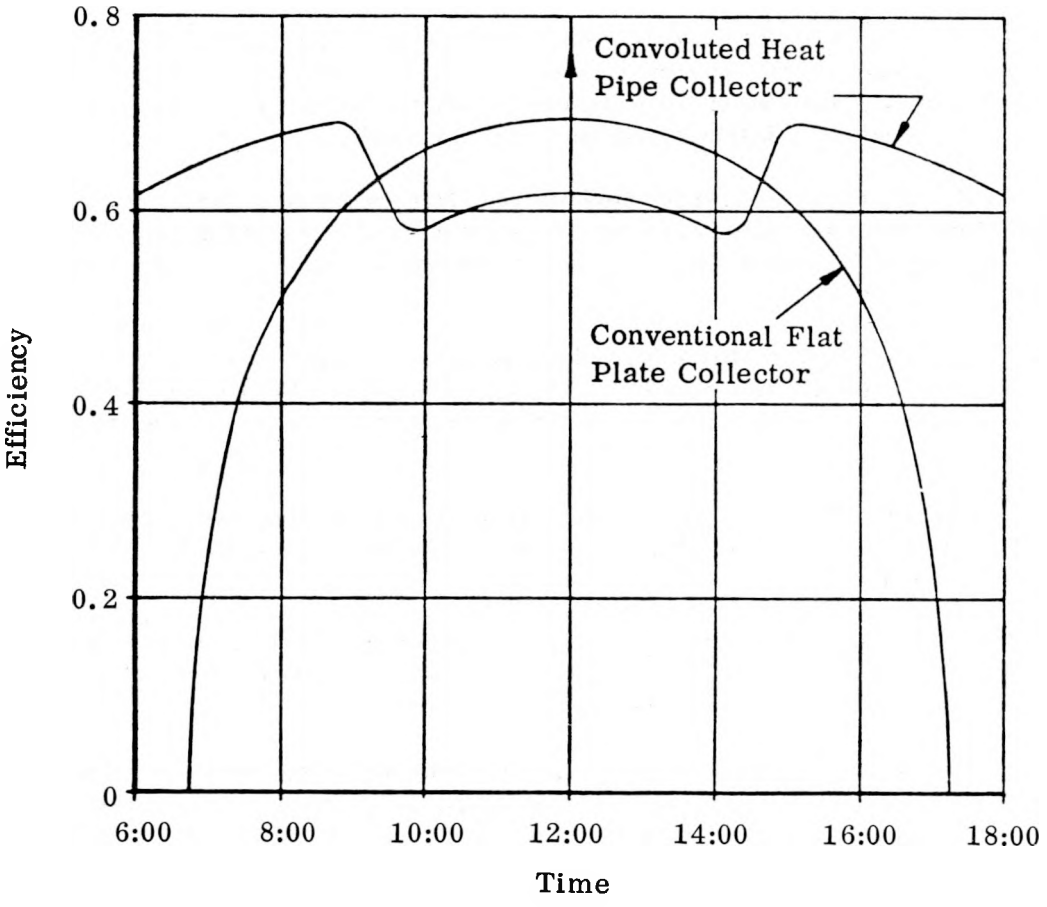


B. Comparison of Efficiency with Identical Flat Plate Collector

Fig. 7 — Heat Pipe Collector with Perpendicular Reflectors



A. Geometry



B. Comparison of Efficiency with Identical Flat-Plate Collector

Fig. 8 — Convoluted Heat Pipe Collector

DISCUSSION

Question (Roger Gillette, Boeing Aerospace): I do not understand how the use of a reflective facet perpendicular to the collector surface can improve efficiency during off-normal solar incidence periods. It appears that shading from the adjacent facet would offset gains. Can you explain this?

Answer: (W. B. Bienert, Dynatherm Corporation): The total energy falling on the absorber is unchanged, but, due to the partial shading and reflection, the solar flux is concentrated on part of the absorber. Assuming the heat pipes are perfect thermal diodes, heat will be collected from the illuminated sections only; the shaded sections do not contribute to heat losses. Hence, the efficiency is improved.

Question (George O. G. Lof, Colorado State University): What large savings are possible in the heat pipe transfer concept to offset the large cost penalty imposed by the heat pipe itself? Efficiency gain does not appear sufficient.

Answer: It is true that heat pipes are not likely to increase collection efficiency significantly. Their main advantage is expected to come from modularization: integral collector units that can be mechanically attached to a manifold, that are completely sealed, and that are freezeproof. As shown in the Annual Technical Report (DTM-75-1), the cost penalty ranges only from 80 cents to $1.20 per square foot.

Question (Ugur Ortabasi, Corning Glass Works): What is the temperature drop expected between the outer wall of the evaporator and the outer wall of the condenser at a radiation level of, say, 200 Btu/hr-ft^2? Do you expect a dependence between the operation temperature of the heat pipe and the fin efficiency F′? If so, explain why. How would this affect the daily overall efficiency of the collector?

Answer: For the indicated insolation of 200 Btu/hr-ft^2 and a heat pipe spacing of 2 inches (typical for a "Roll-Bond® Panel") the predicted overall temperature drop is about 12° F. This ΔT should be independent of operating temperature, since it is governed by evaporation and condensation film coefficients that do not vary much with temperature.

Question (F. John Allen, Garrison, N.Y.): In any discussion of the "thermal diode" function of any heat pipe, mustn't one consider the effect of conduction through the structural wall of the heat pipe, which is necessarily connected over some area of the collector plate? Is this a negligible factor, especially in a water-based storage system?

Answer: The thermal conductance of the heat pipe wall and the attached absorber section from the midpoint of an 8-ft long panel to the condenser is about 0.04 Btu/hr° F compared to approximately 22 Btu/hr° F for a functional heat pipe.

Question (Erik A. Granholm, Bendix Aerospace Systems Division): What are the typical heat pipe fluid working temperatures used for the flat plate solar collector? How can a single type of heat pipe be suited to all thermodynamic processes, i.e., heating, hot water, and cooling?

Answer: Typical working fluid [temperatures] for flat plate collectors are between 100° and 200° F. Several Freons, such as F11, F114, and others, have acceptable vapor pressures and other properties in this range.

Question (Benicio I. Dussan V, Philadelphia, Pa.): Are heat pipes affected by gravity? What is the minimum ΔT attained between the ends of the pipe within the operational temperature range of the solar collector?

Answer: The heat pipes used in solar collectors are gravity aided; i.e., gravity instead of a wick is used to return the condensate to the evaporator. See answer to question by Ortabasi about ΔT.

52,084

FLAT-PLATE SOLAR AIR COLLECTORS FOR AGRICULTURAL USE

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Introduction

TRW has performed research into the application of solar energy to the food drying industry. This paper will describe the analyses we used in the selection of the air collector configuration for the system test to be performed at California Polytechnic State University, San Luis Obispo. Cal Poly's test of a solar augmented crop drying system is being performed under NSF/RANN Grant GI 42944.

Our investigation of the solar system design included both a technical and economic point of view. Subscale components were designed and tested for performance. Economic analyses of the total cost of dried produce versus the parameters of temperature, fuel cost, equipment cost and life, and the alternates of system configuration were made. The results of these studies permitted the choice of the system which I will describe herein. This system has been detail designed and construction is under way. We expect to be drying crops in this facility early next year.

Initially, we looked at the present methods used for dehydrating various food stuffs. Figure 1 shows a typical belt dehydrator. Here the produce is placed on a moving chain belt and hot air is passed thru the produce as it moves thru the machine. Other methods include tunnel dehydrators and bin dehydrators. The principle is the same - heated air is passed through the fruit or vegetable for some period of time. Time and temperature are key factors. Whether you recirculate some of the air is also key to the economics of the system.

Economics

In Figure 2, we have presented the cost of dehydration as a function of drying temperature. Temperature also has an effect on quality of the product.

In order to evaluate the performance of various collectors, we developed a parameter - BTU/$-day. This is the amount of BTU's that can be collected per day per dollar invested in the solar system at a specific operating temperature. An example of the analysis of several collectors at a 160°F drying temperature is shown in Figure 3.

It is seen that the single glazed air collector is the most economic for the greatest range of utilization (% solar to total energy). Figure 4

shows the economics of the solar system as a function of the air temperature. As expected, the lower temperature system is more efficient. The sharp drop around 28% utilization is due to the need to include storage in the system. A change in the operating mode when storage is employed, together with the cost of the storage tanks, reduces the BTU/$-day.

It was found that virtually all solar systems, when used for food dehydration purposes, have a common pattern of behavior. When the solar collector is small, so that it is capable of supplying a small part of the dryer energy requirement (solar energy utilization is 5-10 per cent), a high performance index is obtained. This performance index decreases when the collector size is increased to supply a larger fraction of the dryer's energy needs with the solar collector. When the collector size is increased to provide approximately 28 per cent solar utilization, the performance index drops sharply. Then, if the collector area is increased even more, the performance index may remain the same or increase slightly reading a weak maximum and then decrease. This system characteristic is illustrated in Figure 5. The point where the performance index drops sharply (becomes discontinuous and sometimes double-valued) is when the solar collector starts delivering more heat (for a limited time only) than is required by the dehydrator. At this point, as mentioned above, it becomes necessary to start using thermal storage to store the excess heat. As the storage (which at this point is small) heats up, the fluid temperature entering the collector increases, thus making the average collector temperature higher and lowering the collector efficiency. Decrease in collector efficiency results in less BTU's collected and thus a drop in the performance index. As the collector area is made larger to provide above 40 or 50 per cent solar utilization, the thermal performance is improved. However, large thermal storage requirements and the added investment pulls the performance index down again.

We can transpose the cost index into the common parameter of cost in terms of dollars per million BTU. This data is presented in Figure 6. On this same curve are two limits, one being the cost of natural gas; the other is the cost of liquid propane in the San Luis Obispo area.

Today, due to natural gas shortages and the resultant allocations, crop dryers have been forced to go to increased quantities of liquid propane. It is unquestionably more economical to use an air solar collector system than to switch to liquid propane. As the cost of the fossil fuel goes up, it becomes practical to increase the percentage of solar energy as shown in Figure 7.

Air Collector Design

The collector we conceived consisted of roughly rectangular air ducts running the length of the absorber. Important parameters in the design are the size of duct, length and air flow velocity. For instance, increase in the air flow velocity will improve the heat transfer between the duct walls and the air due to increase in Reynolds number, thus increasing collector efficiency. However, higher air flow velocity increases pressure

drop and therefore increases fan power. It can be seen that all attempts to improve the collector efficiency may result in pressure drops so large that the fan power becomes greater than the BTU's collected. Our study extended the work done by Charters*. An example of some of the data developed by our computer analysis is shown in Figure 8. For this particular case, you can see that the peak net energy collected occurs at a collector length of 160 feet.

The net useful energy is the solar energy collected less the fan power expended. However, we are interested in cost - and electricity costs about 6 times that of natural gas, while motor efficiency is 0.85 and fan efficiency is 0.70. Therefore, the net energy is the solar energy less 10 times the electrical energy.

Subscale Tests

In order to verify some of the analytical tools used, we designed a 4 ft by 8 ft solar air collector. The configuration of this unit is shown in Figure 9. The collector was fabricated from galvanized sheet steel by Cal Poly. Photographs of the test specimen during test are shown in Figures 10 and 11. The glazing consisted of thin transparent plastic film. Two modes of air flow were tested (single pass and double pass). These are shown in Figure 12. The results of these tests are presented in Figure 13. In the early parts of the test program, we had difficulty getting uniform air flow through the collector. This data conforms excellently with the analysis as can be seen from the analytical data points plotted in this figure.

Full Scale Tests

The next step in the confirmation of the analysis of the solar augmented crop drying process is the pilot plant operation. This system schematic is shown in Figure 14. The dryer is a laboratory cabinet dehydrator modified to provide the inlets for the solar heated air. The system is being installed in and on a building provided for this at the Food Processing Laboratory of Cal Poly, San Luis Obispo. Three 2 ft by 70 ft long collectors will be mounted on the roof of the building as shown in Figures 15 and 16. Ducting will be provided such that the collectors can be connected in parallel (as shown), in series, with either single or double pass modes as described earlier. The details of the collector configuration are shown in Figure 17. You will note that the passages are of two different dimensions. This is due to the need to use available steel decking. The glazing is an inexpensive plastic and it is anticipated that it will be replaced every year. This concept is still less expensive than using a much more expensive material with an insignificantly longer life. During the test program, several different plastic materials will be tried to choose the most efficient.

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* W.W.S. Charters, "Some Aspects of Flow Duct Design for Solar-Air Heater Applications," Solar Energy, Vol. 13, 1971, pp. 283-288.

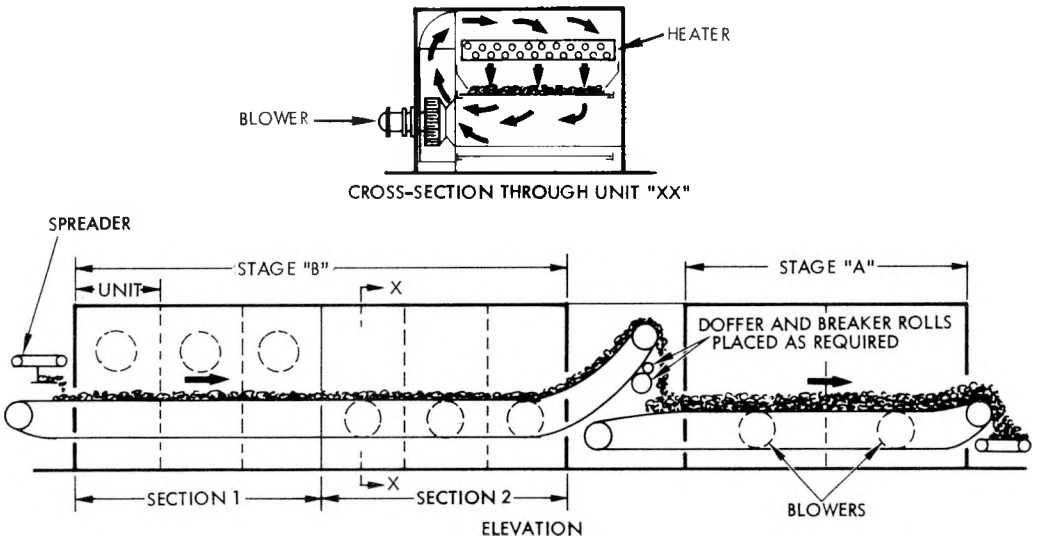


Fig. 1 — Continuous Belt Dehydrator

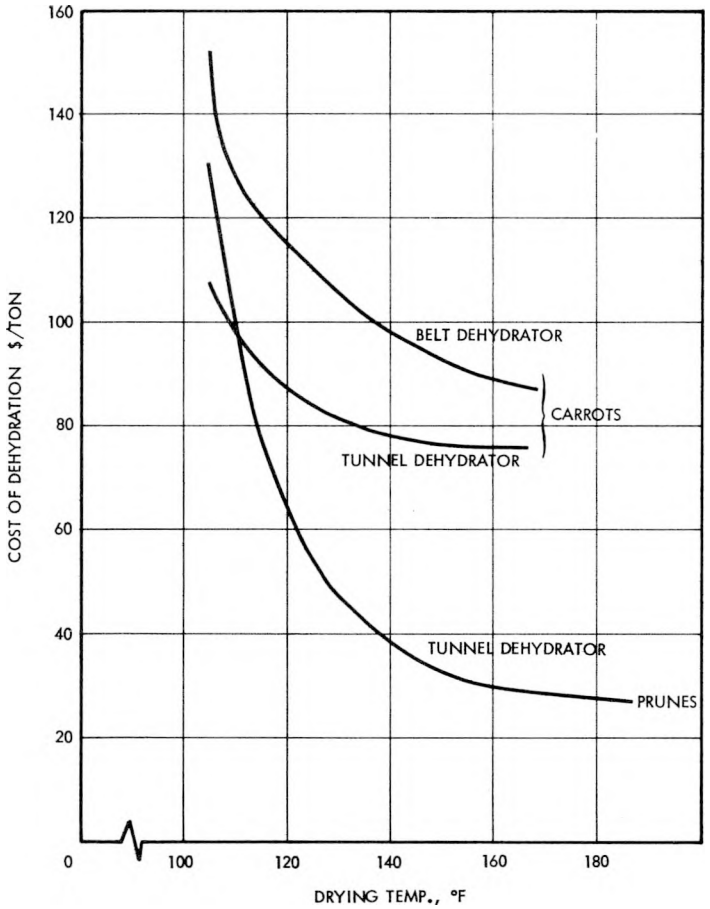


Fig. 2 — Cost of Dehydration as a Function of Drying Temperature

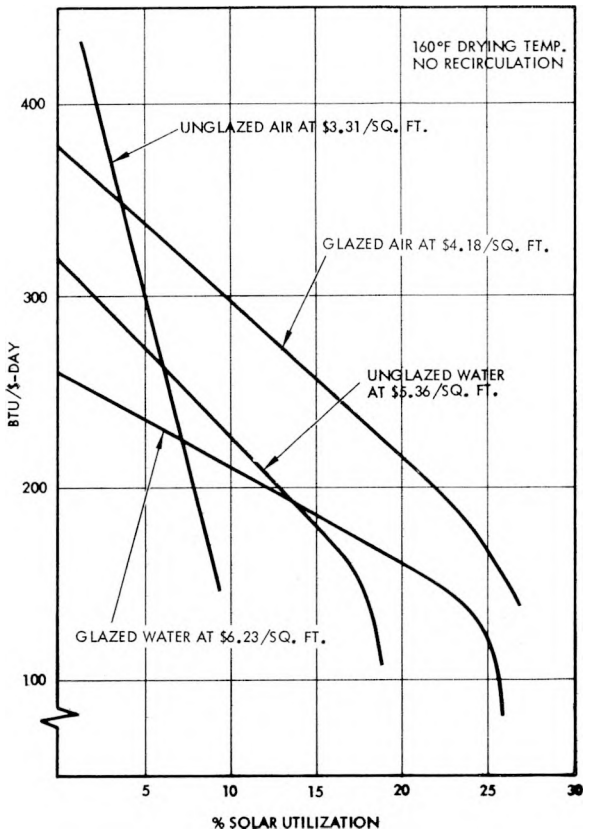


Fig. 3 – Performance Index of Solar Drying Systems
with Several Types of Solar Collectors

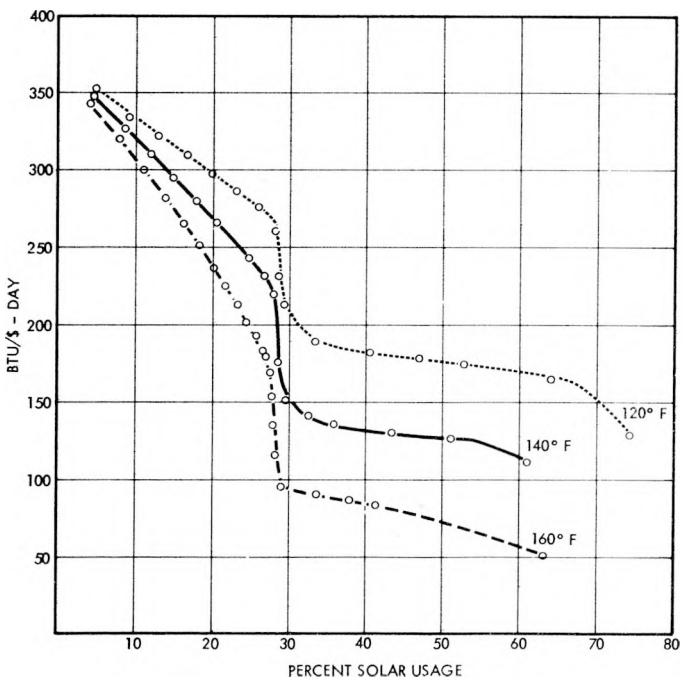


Fig. 4 – Performance Index of Solar Drying Systems Using Air Collectors

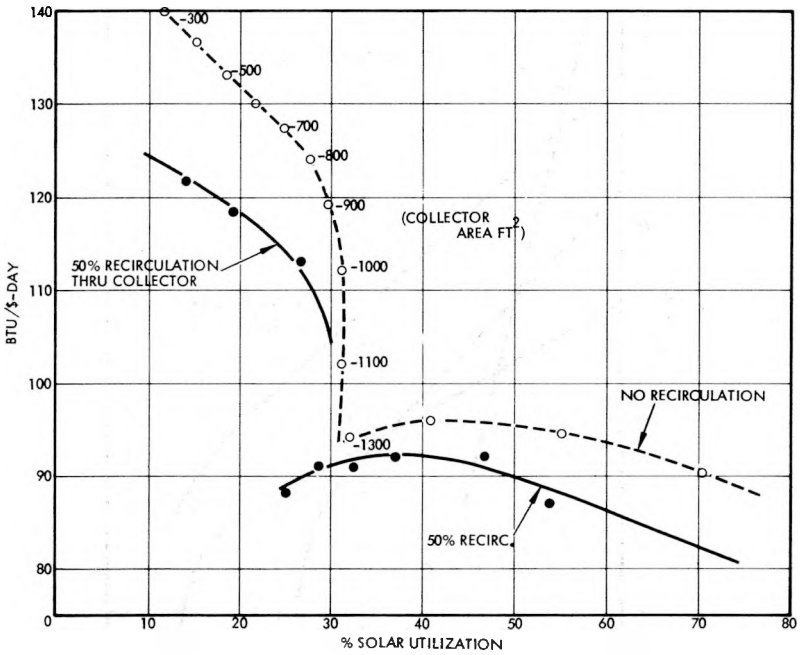


Fig. 5 — Typical Performance of a Solar Dehydration System using Glass-Glazed Air Collectors at 140° F

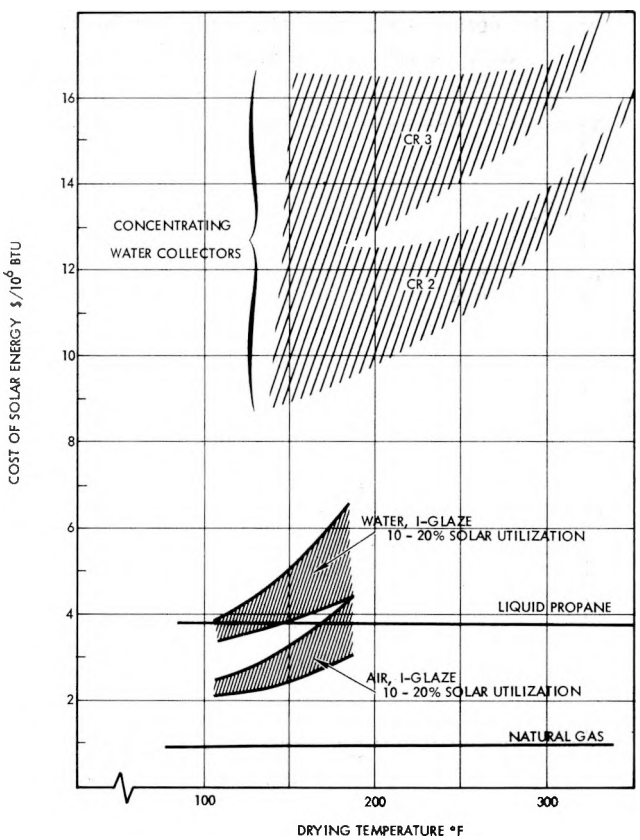


Fig. 6 — Summary Chart Giving Cost of Solar Energy as a Function of Temperature for Various Systems (based on 200-day use per year)

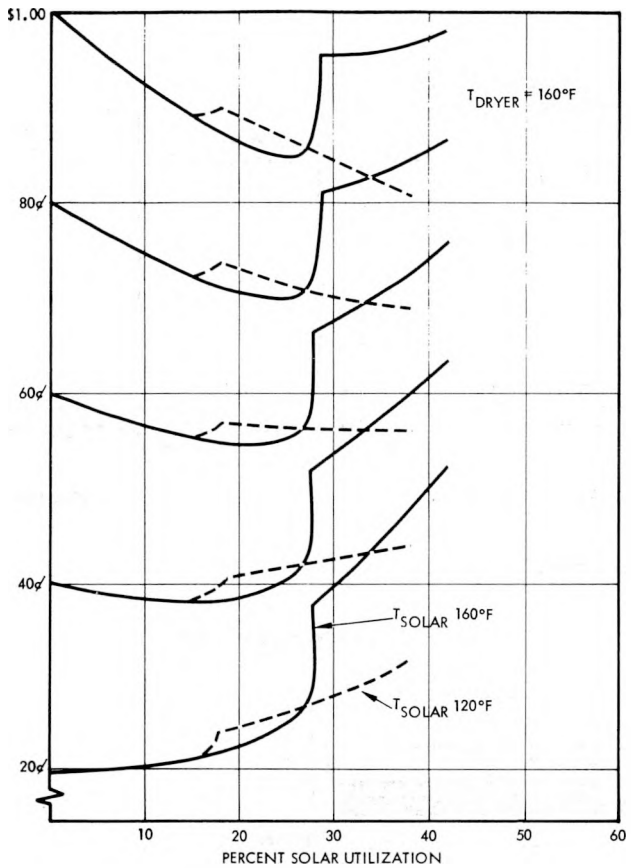


Fig. 7 – Total Dehydration Fuel Costs at 180° F Drying Temperature

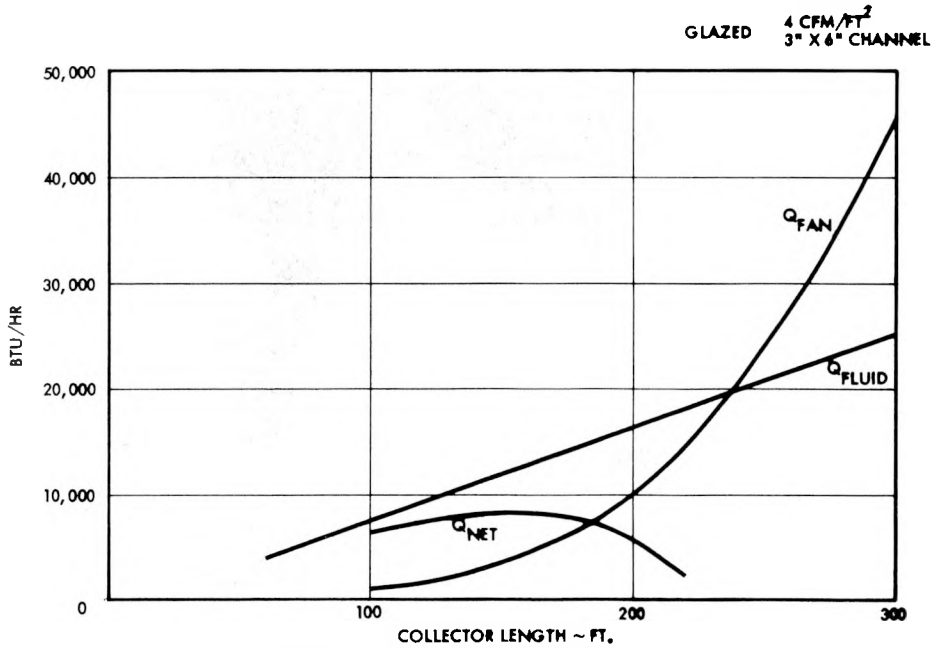


Fig. 8 – Net Energy Collected as a Function of Collector Length

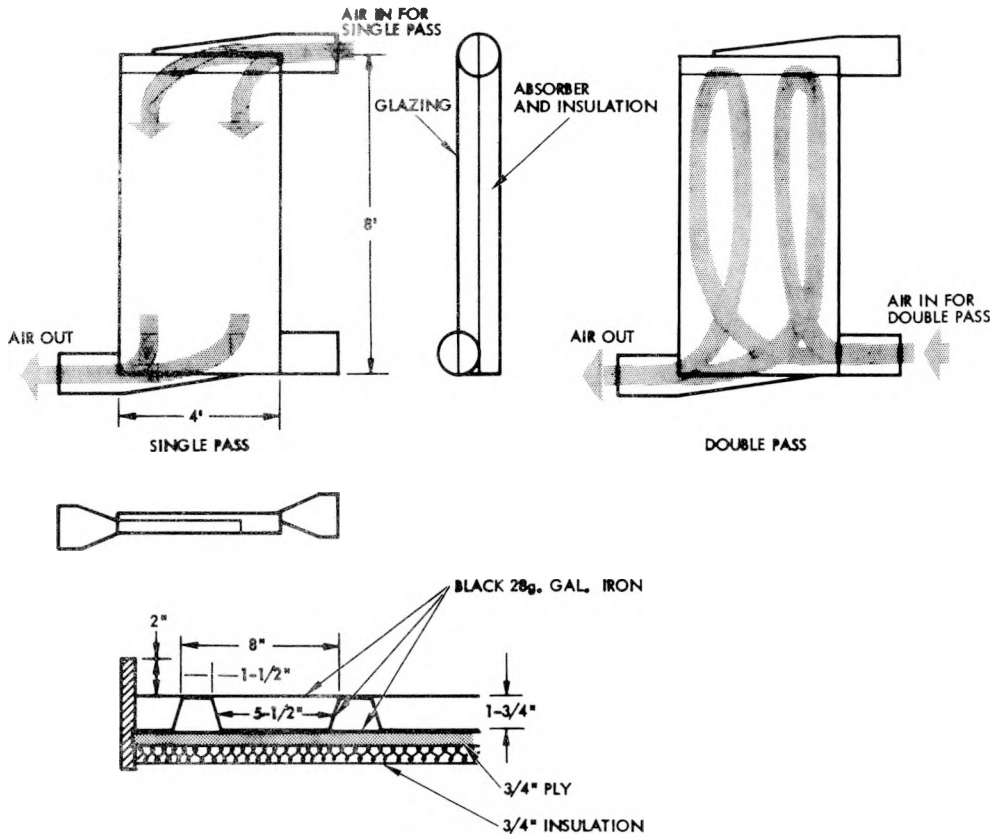


Fig. 9 – Subscale Air Collector

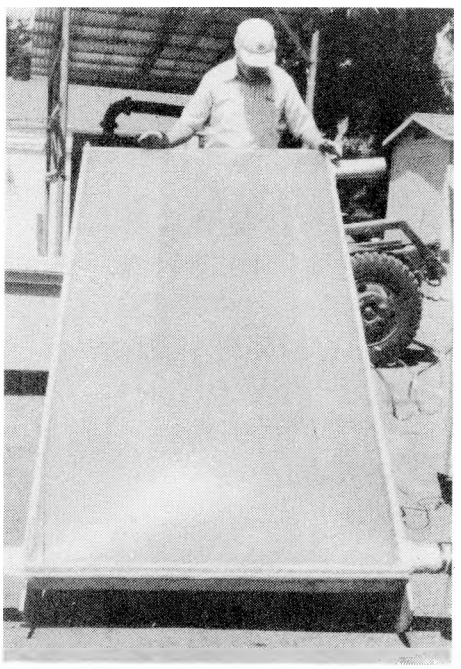


Fig. 10 – Subscale Test Collector

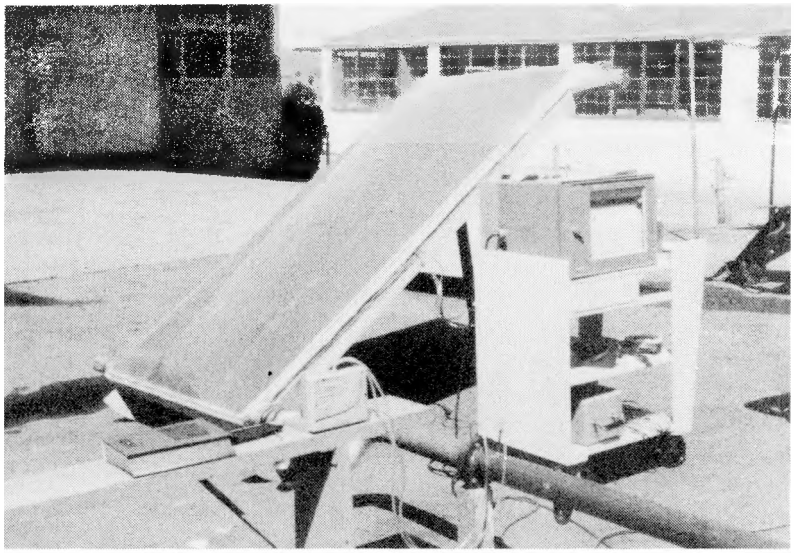


Fig. 11 — Subscale Collector Under Test

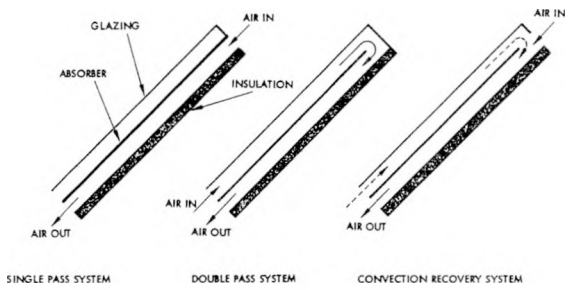


Fig. 12 — Collector Operating Modes

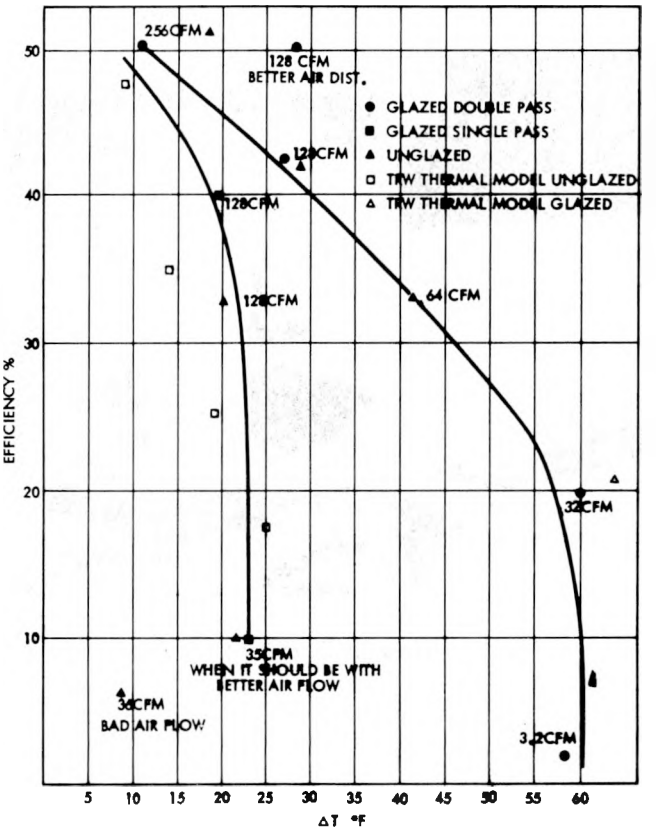


Fig. 13 – Test and Analytical Data for Subscale Collector

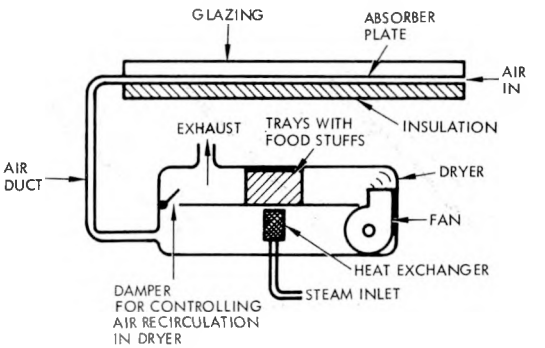


Fig. 14 – Block Diagram of Experimental Solar Dehydration Facility at Cal Poly

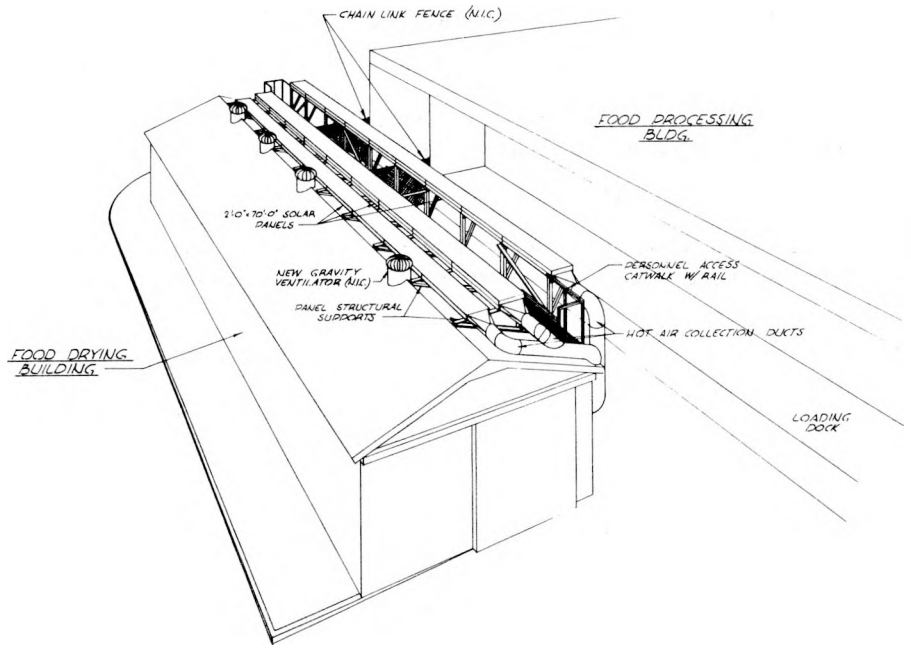


Fig. 15 – Experimental Solar Dehydration Facility at Cal Poly

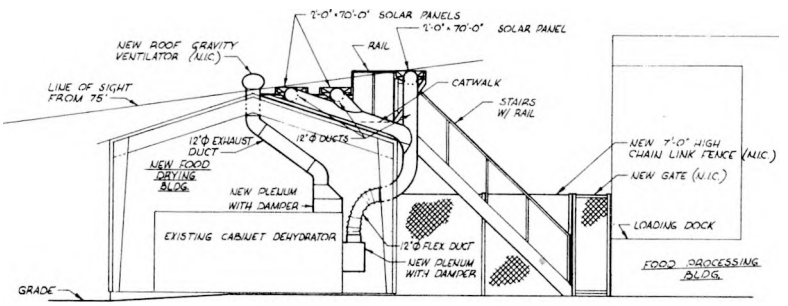


Fig. 16 – Connection of Solar Collectors to Dehydrator

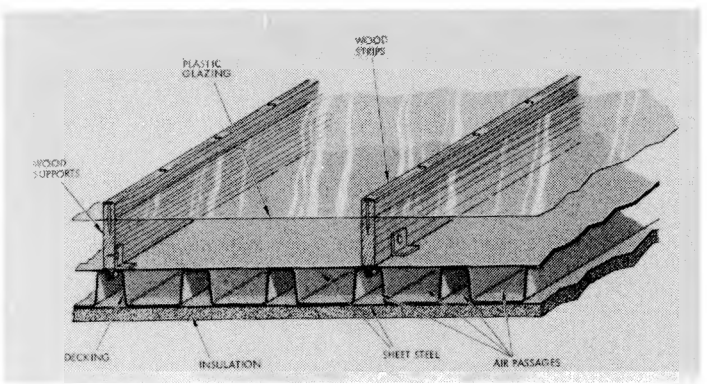


Fig. 17 – Solar Collector

DISCUSSION

Question (Karl W. Boer, University of Delaware): Charters' results cited are for smooth ducts. With fins and rough surfaces, marked improvements are possible. Have you investigated the sensitivity of your system to such improvements?

Answer (Jack M. Cherne, TRW Inc.): We have looked at various sized ducts, from about 3/4 in. by 6 in. to 1½ in. by 6 in. Fins were not considered because we wanted to make the collectors out of commercially available materials.

52,085

PROJECT SUNGAZER*: A VERTICAL-VANED FLAT-PLATE COLLECTOR WITH FORCED-AIR HEAT TRANSFER

Keyes, J. H.
International Solarthermics Corporation
Nederland, Colorado

DURATION OF PROJECT: Project Sungazer was initiated in November 1973, although it was conceived conceptually much earlier. Prototype Testing Programs A, B and C were completed in early January, February and May 1974, respectively. Verification Testing was completed in September 1974. Marketing Research Studies A, B and C were completed in April, July and October 1974, respectively, and aimed not just at comsumer acceptance and pricing considerations but also at a variety of distribution programs. Prototype Manufacturing Plant Program A was initiated in February and completed in May 1974. Prototype Modular Manufacturing Program B was initiated in June and completed in October 1974. International marketing was commenced in October 1974, with completed and on-going negotiations involving in excess of 2500 manufacturers world-wide.

OBJECTIVES: After inputs from marketing and manufacturing, the following objectives were formalized:

1. The total system must be easily compatible to existing housing. The ratio of new housing starts to existing housing would require nearly 50 years to implement a 50% utilization of solar heating in the U. S. even if every new home were equipped, and fossil fuel depletion rates do not permit such a leisurely pace.
2. Installed price of the total system, including labor and profit along the entire distribution chain, must not exceed $5000, preferably less.
3. Engineering had to be oriented toward heat loss reductions in the total system and particularly concerned with inexpensive materials technology if objective number 2 were to be realized.
4. An educational effort would have to be geared toward making the residence ready for solar heating with proper insulation, since no home with typical insulation built in the past 20 years could be economically solar heated. Old values for "economic insulation" were derived from inexpensive fuel costs and were totally inappropriate for the present and future situation.
5. As opposed to traditional "worst case" engineering, auxiliary systems require "average case" engineering, probably the most difficult educational task of all!

*"Sungazer" is a trademark of International Solarthermics Corp.

RESEARCH AND DEVELOPMENT PLAN: R & D assumed the following premise: that many of the existing flat-plate collection systems could function at an acceptable level of energy output. Therefore, engineering should be aimed at heat loss reductions, not just from the collector, but from the total system. To put it another way, "It's not how much you make, but how much you save that counts!" A collection system capable of 200,000 Btu/day is worthless if later systemic losses total 180,000 Btu/day - not at all an unusual case in some systems! Hydronic systems seemed impractical for a number of reasons: (a) although efficient heat transfer from the collector could be effected, the excellent heat transfer capabilities of water were a tremendous disadvantage in achieving long-lived thermal storage where efficient heat transfer during stagnant periods is the very opposite of what is desired; (b) costs ruled out the system in line with pricing objectives; (c) Murphy's law concerning hydronic systems must certainly be, "They leak".; (d) 90% of existing single-family residential housing is heated by forced air, so systemic simplicity alone would dictate utilizations of a total forced-air system; and (e) maintenance considerations quickly made the hydronic system appear infeasible. Therefore, although this workshop will consider the collector independently of the total system, the ISC R & D program was aimed directly at matching components for efficiency and designing an integrated total system - taking into account not just the collector, but thermal transfer to storage, storage, thermal transfer (on demand) to the residence, preparing the residence for solar heating, automatic controls interfacing the components of the system and interfacing the system with the fueled furnace, safety engineering, ease of manufacture and installation, and engineering low maintenance demands.

ACCOMPLISHMENTS TO DATE: The major accomplishments of Project Sungazer have been:

1. A collector which delivers to storage an average of 1200 Btu/ft^2·day throughout the 270 day heating season after accounting for 34% cloud reduction;
2. A collector efficiency of approximately 90% in the typical ratio of total energy transmitted through the covers to the energy usefully transferred to storage;
3. A collector thermal transfer system with associated solid state controls to maintain operation primarily within the most efficient range;
4. Effectively no thermal loss in transfer to storage;
5. Less than 15,000 Btu/day loss from storage, and more typically, 2500 to 5000 Btu/day loss under typical winter conditions;
6. Solution of above-ground collector-storage installation;
7. Factory production of a unitized total system with a 92 ft^2 collector capable of delivery of 29 x 10^6 Btu during the heating season under 34% cloud conditions; and
8. A solar collection system that obtained building department blanket approval without codification of a special solar heating code, using existing building codes, in less than two weeks.

PROBLEMS ENCOUNTERED:

1. Collector covers - Because of high coefficients of linear expansion, plastics require very small panels for efficient sealing, thereby increasing the glazing supports area and concomitantly reducing the useful collection area. Ordinary window glass averaged $1/ft^2 or more. ISC therefore opted to utilize .1875 in. "float" glass at 30 to 50¢/ft^2. Transmissivity was found to be reduced less than 2% at 0° angle of incidence. In order to reduce glazing support areas and sealing problems, huge panes (6ft. x 8ft.) were used. The two covers were not bonded together, but allowed to expand and contract independently of one another, eliminating thermal breakage of covers.
2. Collector plate -
   a. Reflective losses - An often ignored major loss from the plate is the amount of reflective losses of short-wave radiation transmitted through the covers to the plate. Murphy's 2nd and 3rd laws relating to collectors must be, "They get dirty" and "The paint deteriorates." Although one may have initial losses of less than 5% due to reflection from the black plate, after months of usage they may become as high as 15%. The vertical-vane configuration tends to minimize these losses due to internal reflection to another surface inside the collector.

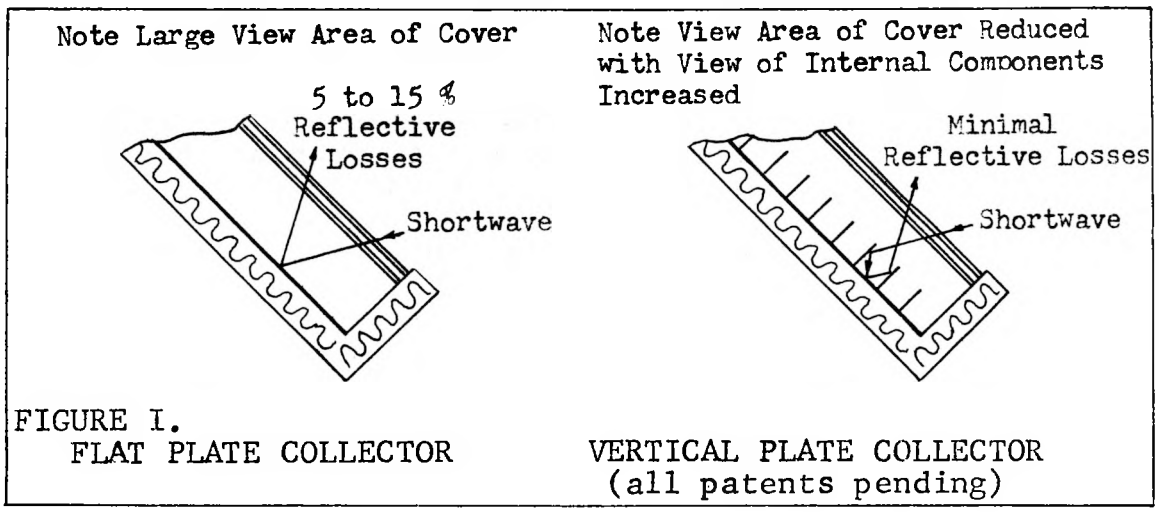


FIGURE I.
FLAT PLATE COLLECTOR — VERTICAL PLATE COLLECTOR (all patents pending)

Although cylindrical cups 2.75 in. dia. x 2.0 in. high were utilized, a number of other methods for achieving the same end suggested themselves readily, and patents were applied for on those configurations as well. The vertical plate permits the utilization of inexpensive oil-based, high-temperature flat black paint. With forced-air transfer, no thermal bonding of the internal collector elements was required, and simple gravity loading was utilized.

   b. Radiative losses - The amount of radiative losses from the collector has not been determined, but as shown in Figure I, these losses are reduced in proportion to the "view area" of the cover throughout the vanes.

c. Convective and conductive losses - The utilization of forced-air transfer required engineering to achieve efficient transfer, due to the low specific heat and specific weight of air. A high-pressure, high-velocity air stream is interfered with effectively enough by the vertical vanes to cause very efficient thermal transfer, with the airstream temperature approximately equal to the plate temperature during operation.

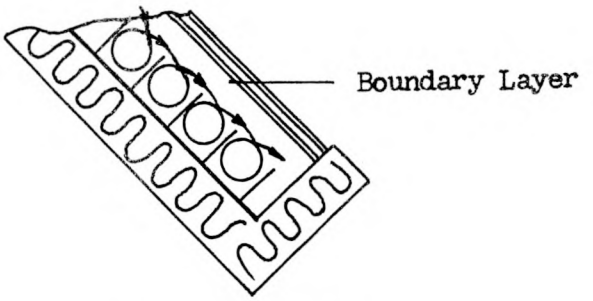


FIGURE II. COLLECTOR "WASHING" BY FORCED-AIR TRANSFER

Further, however, by sufficient separation of the vanes from the cover, a boundary layer is established by near laminar flow next to the cover, significantly reducing the cover temperatures, particularly in comparison to typical hydronic systems in operation. Hence, conductive-convective losses through the cover are reduced significantly. A minor addition which further impedes exchange between the cover and the outside environment is a series of small protrusions past the cover at glazing support intersections to interfere partially with convective transfer from the cover.

3. Sealing problems - It was found that high-temperature, water-based acrylic caulking has an excellent "memory" necessary to compensate for the expansion and contraction of large sheets of glass. Butyl caulks were found to be inadequate.
4. Reflectors - The energy actually transmitted through the covers can be increased an average of 35% during the heating season to a collector at a 60° angle at 40° North Latitude. Polished aluminum sheeting is expensive, but not equivalent to 35% of collector cost, so is economically justified. The main problem is break-down of the surface after several years of exposure, requiring an expensive maintenance amortization. ISC's solution was to bond a foil surface to a rigid surface. Replacement is with contact adhesive-backed foil every two or three years at a cost of about $5. Initial cost is, of course, also reduced significantly by use of foil in lieu of polished sheets. By hinging the reflectors at the base of the collector, protective doors are formed to protect the collector surface during the high-yard use summer months.

5. Thermal transfer - To minimize heat losses, the collection system was designed so that the airstream travels only 8 in. from the collector plate to storage.

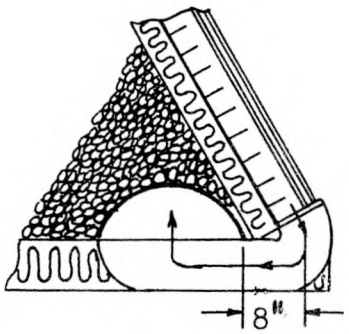


FIGURE III. VERTICAL PLATE COLLECTOR-STORAGE AREA, SECTION.

As can be seen in Figure III, an additional cost savings was achieved by use of a coextensive planar insulation wall between the collector and storage.

6. Collector controls - Simple thermostatic controls were found to be inefficient and impractical. Therefore, a complex solid-state circuit was designed. Relays become unreliable after some period of use, so triacs were utilized for switching. High and low voltage components were connected optically to provide safety. A simplified diagram of the controls is shown in Figure IV.

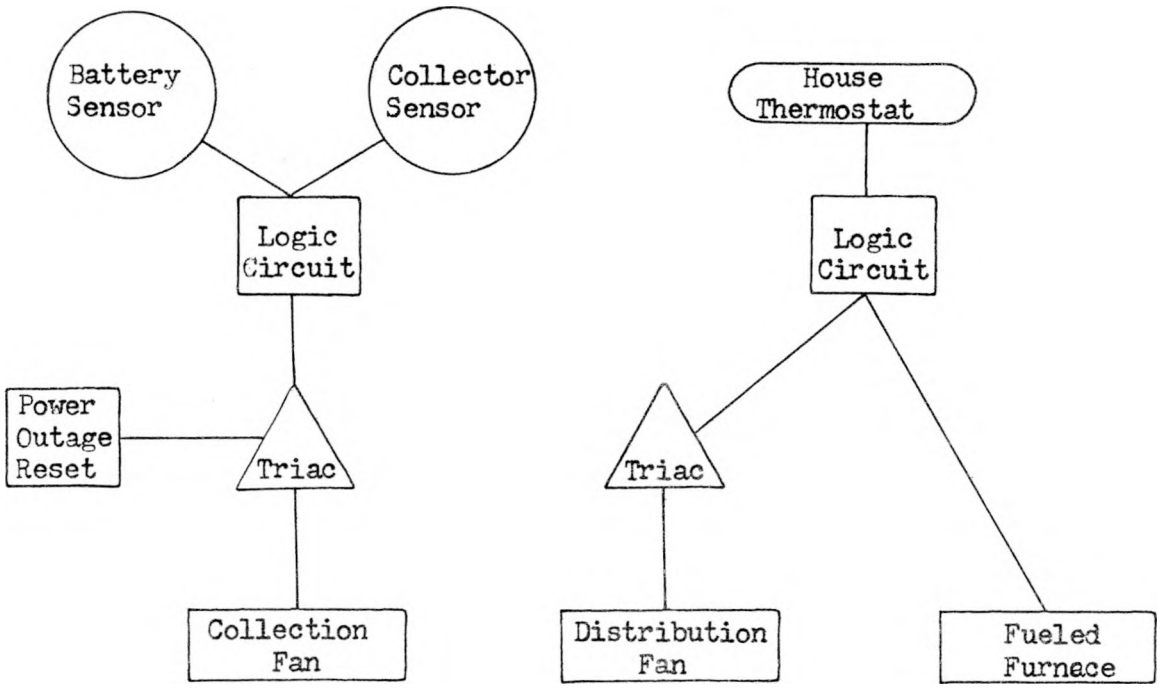


FIGURE IV. CONTROLS

The power outage reset mode is necessary to prevent thermal breakage of covers if a power outage should occur during midday times, since stasis temperatures of about 360 °F are achieved very rapidly on the vertical-plate collector in the absence of forced-air convection. This reset mode cycles the collection fan off and on in short bursts after a power outage to equalize component temperatures gradually, before resuming normal operation.

7. Collector installation - Since few existing residences have a 45 to 60° pitch, oriented to the south, rooftop mounting of the collector on existing homes is economically and practically unjustified. Ground-level mounting therefore became appropriate. Above-ground storage was also required for existing residences, since many yards do not permit entry of heavy earth-moving equipment, and no housewives would. Rigid polyurethane foam sandwich panels solved dozens of construction problems and permitted non-excavation installation of the unit. Modular construction permitted maximum flexibility.

RELATION OF PROJECT TO U.S. DEVELOPMENT EFFORT: The manufacturers being licensed by ISC to produce the backyard solar furnace are utilizing a wide variety of distribution and marketing techniques. Many of these will be in the marketplace nationwide with their own name-brand solar furnace by February 1975, and all of them should be delivering units by the Fall of 1975. Marketing estimates place the number of units delivered and installed before the end of the Summer of 1976 between 200,000 and 1,500,000 in the United States alone. This latter number would represent a 2% market penetration during the next 18 months.

POTENTIAL USERS: Obviously the Sungazer Project was aimed directly at the largest market - the existing single-family residence. In that marketplace, present reports indicate primarily propane and electrical heat users and new home construction constitute the majority of demand, although the suburban market is growing in relation to the rising cost of natural gas. Other solar projects under way, but not yet completed, are in the commercial-industrial use areas and in the transportation markets. The areas of solar-electrical generation and solar-mechanical generation seem particularly promising.

DISCUSSION

Question (Harold G. Lorsch, University of Pennsylvania): How do you define efficiency as 90 percent when most other people can barely achieve 50 percent? Your definition is different from other people's. Please state your collector efficiency in the terms that the rest of the world is using: heat collected divided by total insolation falling on the collector outer surface.

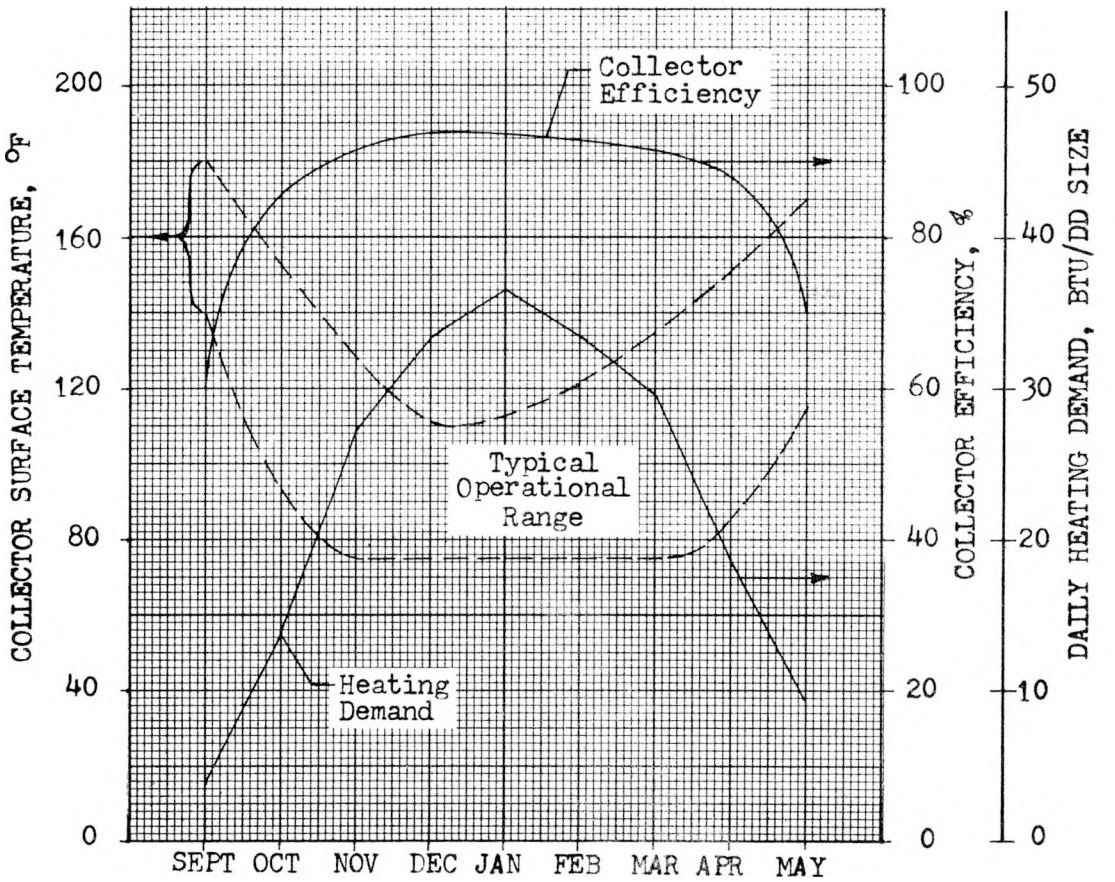
Answer (John H. Keyes, International Solarthermics Corporation): ISC believes that collector efficiencies can be best compared using numbers independent of collector orientation and fenestration. We are not alone in this belief. For example, I refer you to John Yellott's article in the December 1973 *ASHRAE Journal.* The graph on page 37 of that article (courtesy D. Erway) shows typical flat plate collector efficiencies at an ambient temperature of 70° F. This graph shows that a collector with two cover glasses will operate at approximately 80 percent efficiency when the absorber temperature is 80° F. Since the maximum transmissivity of two cover glasses is approximately 77 percent, it is apparent that the definition being used is ISC's definition, i.e., the ratio of heat usefully collected to the total solar radiation transmitted through the covers.

It is unfortunate that the efficiency definition noted in your question gives lower numbers. We in no way represent our unit as superior simply because the efficiency definition utilized gives a higher range of numbers.

Question (Frank Kreith, Environmental Consulting Services): (1) What are the "typical" conditions under which the Sungazer® has an efficiency of 90 percent? (See page 2 of your handout.) (2) Is the curve showing 50 percent at 180° F efficiency based on data? What is the flow rate of air and the energy collection rate at 180° F? (Curve is on page 3 of *Solar Performance Handbook.*)

Answer: (1) As shown in the attached figure for Denver, Colo., the typical operating conditions vary from month to month. The collector efficiency, defined as the ratio of the amount of heat usefully transferred from the collector to the total solar radiation transmitted through the covers, ranges from a low of 60 percent in September to highs above 90 percent during the peak demand months of December, January, and February. The low efficiencies during September and May are not detrimental to the performance of the unit, because for most installations the unit is overproductive during these months. The system was purposely engineered in this manner to take advantage of the higher collector efficiencies that are achieved when the collector surface temperature is between 75° and 125° F.

(2) The curve shown on page 3 of our *Specifications and Performance Handbook* is based on test data between 100° and 150° F. The curve has been extrapolated for collector surface temperatures outside this range. We do not have test data for 180° F because, as shown in the figure, our collector will never operate at this temperature, except possibly in early September when the storage temperature is above 175° F and the house does not require heat.



Collector Efficiency for the ISC Backyard Solar Furnace Model 128 During Typical Operation on a 5000 Degree Day House in Denver, Colorado

Question (Gary C. Vliet, University of Texas at Austin): You quote 90 percent efficiency based on heat recovered to heat passing through cover glass(es). However, you also indicated 5-15 percent absorber reflective losses. In addition, there are convective losses through the front, conduction through the back, and filtration losses. How do you justify your 90 percent efficiency, even based on your definition?

Answer: These losses are characteristic of typical flat plate collectors, but not of ISC's vertical-plate collector. It is apparent that the vertical-plate design minimizes these losses, since collector efficiencies greater than 90 percent have been achieved.

Question (George O. G. Lof, Colorado State University): Since there is no possibility that your claimed thermal outputs can all be of solar origin, have you added in the thermal equivalent of the high electric power use in circulating air through this very small collector?

Answer: I am curious as to how you arrived at your statement, ". . . there is no possibility that your claimed thermal outputs are of solar origin . . .," because most of our thermal outputs are of solar origin. There are, of course, thermal inputs from the work delivered to the airstream by the fans, but this energy is relatively insignificant since the fan motor is only one-half horsepower. Very little, if any, of the heat dissipated by the motor is input to the system, because the collector-blower assembly is insulated from storage.

Perhaps you failed to account for the solar input from the collector mirrors. This contribution ranges between a low of 30 percent at the winter solstice to a high of 36 percent at the equinoxes, for an overall average increase of approximately 34 percent for the 270-day heating season. You can verify these values given the following:

- Solar constant (442 Btu/ft^2-hr)
- Transmission coefficient for unit air mass (generally assumed equal to 0.81 on a clear day)
- Relative air mass
- Sun position (altitude and azimuth angles as a function of time)
- Orientation of unit (faces south with collector inclined 60° from the horizontal)
- Ratio of diffuse sky radiation to direct solar radiation
- Optical properties of collector covers (transmissivity as function of incident angle)
- Mirror reflectance (0.95)

The equations necessary for the computations may be derived from simple trigonometry, or they may be obtained from my book, *Harnessing the Sun,* Conestoga Graphics, Denver, 1974.

Question (Byard W. Wood, Arizona State University): The collector surface area for your system is below, by a considerable amount, that of most installation designs. In a previous article distributed by your company, a statement was made that declared that your collector collected and transferred more energy than the solar energy incident on the collector. Please explain.

Answer: To the best of my knowledge, no such article exists. If you have the article, I would appreciate receiving a copy of it. Thus far we have been unable to violate the first law of thermodynamics, and we really don't hold high hopes of doing so in the near future.

Question (Walter A. Stark, Jr., Heat Recovery Systems, Inc.): (1) Problems with glass breakage? (2) Do you have any plans for the adaptation of this system to solar or solar-assisted cooling.

Answer: (1) Yes, ISC has experienced some problems with glass breakage, particularly due to thermal shock. This has been minimized by modifying the control system so that the collector is not subjected to cold air when it is very hot, e.g., after a midday power outage. ISC has also determined that collector framing and sealing are important in preventing glass breakage. The glass must be allowed to expand and contract with changing temperatures. In addition, care must be taken during installation to insure that the edges of the glass are not nicked and the framing is flat so that the glass is supported evenly.

(2) No, ISC has no immediate plans to adapt this system for solar cooling, because we are developing a solar electric generator that can be used to operate cooling systems as well as other equipment. Our analysis shows this to be a more cost-effective approach.

Question (Dennis A. Ross, Rensselaer Polytechnic Institute): Why do you suggest 12 in.-16 in. of normal batt insulation in the attic? The U value of 16 in. of insulation is not much better than 8 in.-10 in. of insulation. Why not choose a better form of insulation, such as 4 in. of polyurethane foam?

Answer: The improvement in the U value in going from 10 in. to 16 in. of insulation is indeed significant. For instance, assuming typical inside and outside heat transfer coefficients (1.65 and 6.0 Btu/ft^2·hr·°F, respectively) and fiberglass batt insulation with a thermal conductivity of 0.025 Btu/ft·hr·°F, you obtain overall U values of 0.029 and 0.019 Btu/ft^2·hr·°F, respectively, for 10 in. and 16 in. of insulation. This represents an improvement of approximately 57 percent.

One reason that minimal insulation thicknesses have been used prior to this time has been that fuel was cheap enough to allow heat losses to be ignored. Increasing fuel costs and the switch to solar energy have changed this. Another reason for the minimal thicknesses is that it has been to the interest of the builder to minimize construction cost at the expense of operating costs.

The choice between fiberglass, polyurethane foam, or some other form of insulation is one of economics and space available to accomplish retroinsulating.

Question (Peter C. Green, W. R. Grace & Co.): (1) How many systems installed at a profit? (2) How many being installed right now? (3) How many back ordered? (4) What materials improvements needed? (Specific properties)

Answer: (1, 2, and 3). ISC does not manufacture or sell units. We license the fabricating manufacturers under our letters of patent.

(4) ISC experimented with various materials before selecting the ones that are presently recommended to our licensed manufacturers. We believe these materials provide a practical, long-lived unit at a reasonable cost. It should be noted that the current design consists of very few of the materials that were used in the original prototype unit.

It is anticipated that our manufacturers will be making design changes in the future to make use of new materials that are not presently available. Additional changes may also be required to adapt the unit to local climatic conditions.

Question (William B. Zimmerman, Island Earth Designs): (1) Have you considered the commercial viability of offering a guaranteed home heating service on a contractual basis similar to that offered by some oil heat companies? (2) What would the cost for this be in dollars per million Btu.

Answer: (1) Yes, briefly. We discarded the concept, feeling that private, individual ownership of solar systems is to be preferred to developing (long range) yet another energy cartel.

(2) We did not develop profit projections for leasing. The cost to the consumer (exclusive of interest charges) is approximately 56 cents per million Btu for electricity to power the fans. This does not include amortization of equipment, since for the consumer this represents a real-property investment, not an expense. If his home appreciates in value, as has been the case in the past, the homeowner will make a *profit* on his investment when he sells.

SESSION 3

FOCUSING COLLECTORS

52,086

COMPOUND PARABOLIC CONCENTRATORS

Vaclav J. Sevcik, Roland Winston
Argonne National Laboratory
Argonne, Illinois

Objectives:

The objective of this program is to explore the performance of several versions of the Compound Parabolic Concentrator (CPC) collector and to assess its applicability to economic utilization of solar energy for heating and cooling of buildings, central power, and photovoltaic power generation. With the CPC, it is possible to concentrate solar energy by a factor of 10 or so without diurnal tracking.

Background:

The CPC is a non-tracking solar collector consisting of two sections of a parabola located symmetrically about the collector midplane. The two sections form a single curvature, or trough-like solar concentrator with an angular acceptance of $2 \times \theta_{max}$ as shown in Fig. 1. The concentration factor may be shown to be

$$d_1/d_2 = (1/\sin \theta_{max}).^{1}$$

The concentration factor is defined as the ratio of the frontal entrance area d_1 to exit area d_2. The theoretical length or height of the collector can be shown to be

$$L = (1/2)\ (d_1 + d_2) \cot \theta_{max}$$

However, it turns out that the theoretical height can be reduced considerably (30-50%) without having any substantial effect on the performance of the collector. The actual height to aperture ratio for the 10:1 collector is shown in Fig. 2. Also shown is the number of hours that the collector will collect sunlight. Figure 3 shows the average number of reflections for a ray of sunlight as it enters the concentrator. Thus, it is apparent that this 10:1 concentrator can collect light over 7 hours at the worst time of year, and with an average of just about 1 reflection.

Project Description:

The plan is to fabricate several versions of the compound parabolic concentrator. Concentration ratios, i.e., collector frontal area versus energy absorption area of 3, 5, and 10 have been decided upon, somewhat arbitrarily, for prototype design, construction and testing. Two basically different versions of the collector have been produced at this time. In one version, a large number of 3" high troughs are arranged parallel to each other in a panel,

* Work performed under the auspices of the U.S. Atomic Energy Commission and the National Science Foundation.

1) R. Winston, Solar Energy, October 1974; V. J. Sevcik, et al., International Solar Energy Society, U.S. Section Meeting, August 1974.

much like a flat-plate collector (Fig. 4). In the other version, a single large unit of each concentrator (3 ft high and 4 ft long) has been fabricated. In addition, heat receiver systems of various designs will be tested in conjunction with both versions of the concentrator.

The 3:1 flat-plate version of the concentrator has been tested and therefore will be described in more detail. The principal characteristics of the collector are that it concentrates the sun's energy by a factor of 3 and that its angular acceptance (full angle) is 38°. The large angular acceptance implies that bi-annual adjustment of the collector orientation is sufficient to accept direct solar radiation. The modest concentration factor of 3 was chosen to permit efficient operation at ≈ 120° above ambient temperature.

The experimental results from outdoor tests show good agreement with a detailed theoretical analysis[2], and confirm the expected improvement in performance resulting from concentration.

Details of Construction:

The collector consists of a black absorber plate, an array of 20 mirror bars with the compound parabolic profile shape, and a plexiglas cover, and the entire assembly is insulated. The absorber plate is roll-bond aluminum panel painted with a non-selective black, having an absorbtivity of ≈ 92%. For the prototype unit, the mirror bars (48 in long by 3 in high) were cast of epoxy resin from a master mold. The reflective surface is evaporated aluminum deposited on the sides and bottoms of the bars (reflectivity over the solar spectrum ≈ 88%). The plexiglas cover (1/4 in thick) transmits ≈ 86% of the solar spectrum.

Description of Experiments:

Tests were conducted outdoors at Argonne National Laboratory during October-November 1974. The collector was mounted on a tilted platform approximately normal to solar noon. The incident solar radiation was monitored by three Epply pyranometers with the following geometrics: 1) horizontal, 2) on the tilted collector plane, 3) on the tilted collector plane, but masked for an angle of 38° (the acceptance angle of the collector). The heat output of the collector was determined by flowing a 50% mixture of ethylene glycol and water and measuring the temperature rise in the collector and the flow rate. The flow rate was made sufficiently high (≈ 0.3 to 0.5 gpm) to maintain the collector fairly isothermal. To measure performance at elevated fluid temperature, the fluid was preheated. For diagnostic purposes, 24 temperatures of various points on the collector were monitored. The output of the three pyranometers were recorded, as well as the wind speed and direction. The useful data was obtained only in clear sky conditions with stable pyranometer and temperature readings. This is because of the epoxy mirror bars which have large thermal capacity.

Experimental Results:

Flat-plate collector without concentration: when the mirror bar assembly is removed what is left is a simple flat-plate collector. The data with this configuration serves to calibrate the data taking system. A convenient form to present results is to plot $Q_{out}/S \cdot A$ vs $(T_c - T_a)/S$, where

2) J. F. Kreider, Environmental Consulting Service, Inc. Report, 1974.

Q_{out} = heat extracted (Btu/hr)

S = insolation (Btu/hr ft^2

A = collector window area

T_c = average collector plate temperature

T_a = ambient temperature

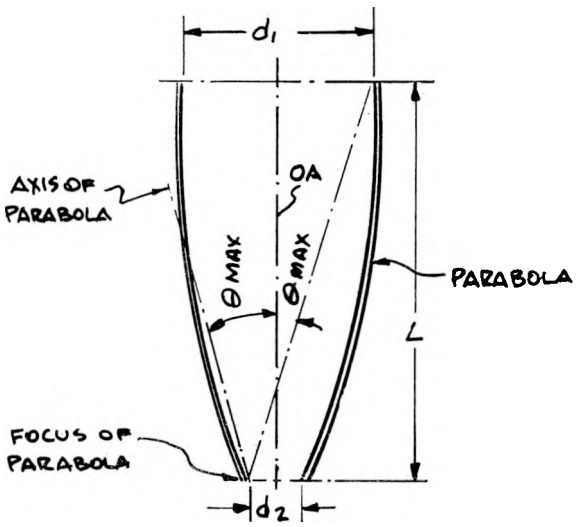
One expects an approximately linear plot in these variables. This is shown in Fig. 5. The relevant parameters are the intercept at $T_c \rightarrow T_a$, and the slope. From these one infers the non-thermal loss efficiency η (o) = 79%, and the heat loss coefficient U = 1.05 Btu/hr ft^2 ^oF.

Flat-plate collector with 3:1 concentration: A similar plot of our data with mirror assembly in place is shown in Fig. 6. In this plot, we have divided by the insolation S' measured by the masked pyranometer, and the area A^1 = 15.36 ft^2 (8% of the window is obscured by the mirror assembly). From this data, we infer η' (o) = 81% and the heat loss coefficient U = 0.65. The effect of concentration on suppressing heat loss is clear from comparing Figs. 5 and 6. To convert these to more useful values, note that on a clear day the masked pyranometer detects 92% of the total insolation. Also, the relevant area for heat loss is the collector plate area A = 16.67 ft^2. The converted values are η (o) = 75% and U = 0.60.

In order to compare the findings with theory, it is necessary to know the back and edge thermal loss coefficient of the collector box. This was measured by covering the front of the collector with 6 in of styrofoam plus 1.5 in of fiberglas and measuring the heat loss. For this configuration U = 0.32, allowing for heat loss of even this thick front insulation, it is estimated that U_{box} ≃ 0.20 to 0.25. Thus, the conclusion is that the 3 fold concentrating collector is characterized by η (o) = 75% U_{front} value is in good agreement with the results U_{front} calculated by Kreider.[2]

Conclusions:

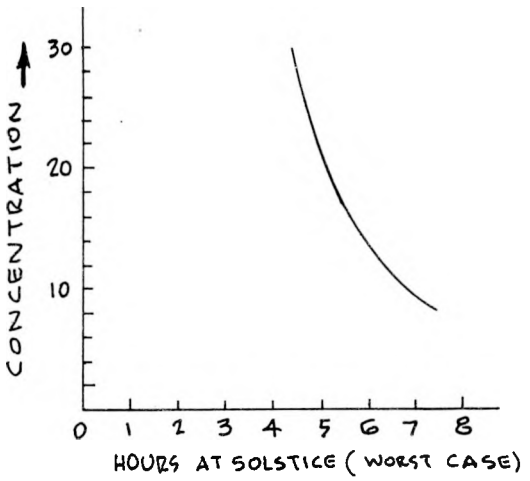
We have shown that the 3:1 compound parabolic collector in a flat-plate configuration has a clear day optical efficiency which is ≃ 95% that of a simple flat-plate collector with a single cover. The U value for frontal heat losses lies in the ragne 0.35 to 0.40. Extrapolating to a practical system, we note that a glass cover with 90% transmission and back insulation with U_{box} ≃ 0.1 are obtainable. This would give performance characterized by η (o) ≃ 78%, U ≃ 0.50. Such a collector would have, for example, 50% efficiency at 130^oF above ambient, and an insolation of 240 Btu/ft^2 hours. This may be a useful range for solar air conditioning applications.



$$(d_1/d_2) = (1/\sin \theta_{MAX})$$

$$L = (1/2)(d_1 + d_2) \cot \theta_{MAX}$$

Fig. 1 – Compound Parabolic Collector. Developed to Concentrate Cherenkov Light in High Energy Physics Experiments. Hinterberger and Winston (1966). Winston (1970).



CONCENTRATION	HEIGHT / APERTURE	ANGULAR VIEW ($2\theta_{MAX}$)
3:1	1.25	38°
5:1	2.0	22°
10:1	3.0	10°

Fig. 2 – Concentration Ratio vs. Time, at Winter Solstice

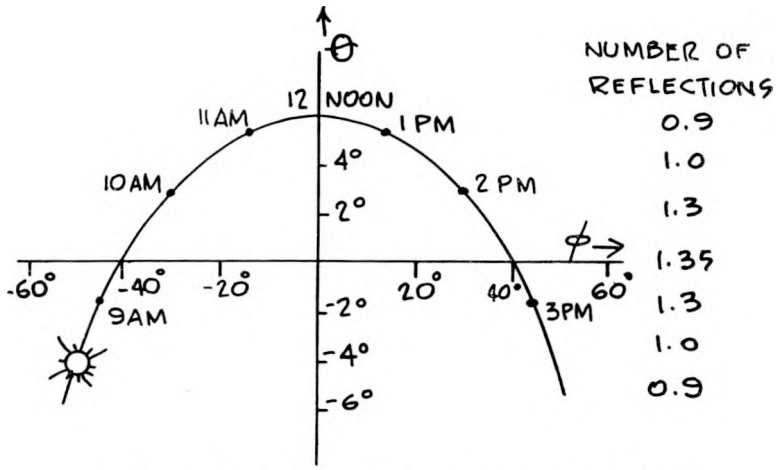


Fig. 3 — 10:1 Concentrator on a Winter Solstice (worst case)

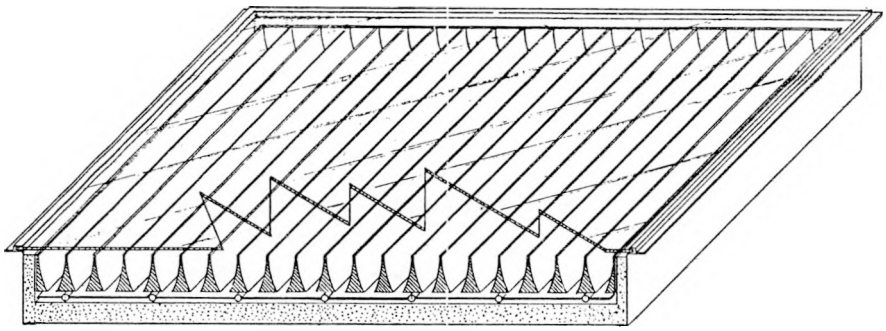


Fig. 4 — 3:1 Concentrator in 48- by 48-in. Test Panel. Scale: None

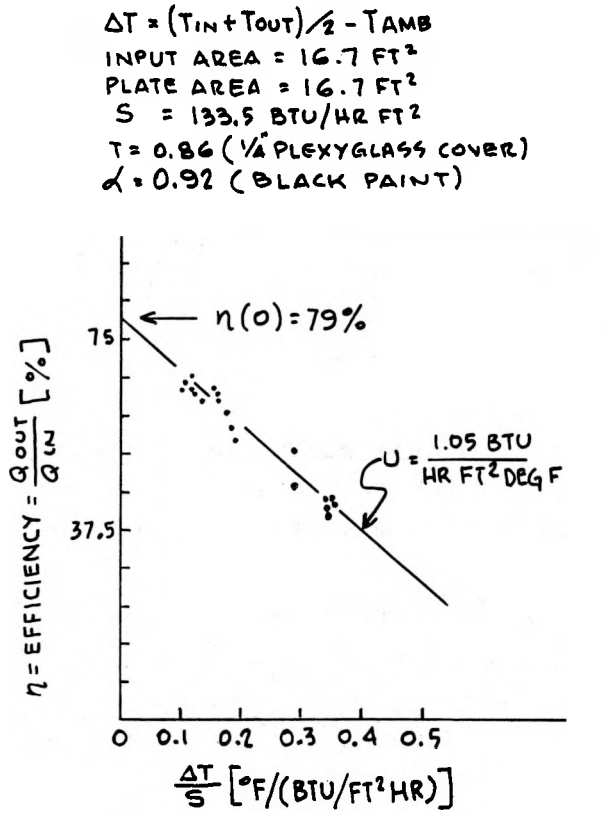


Fig. 5 — CPC Box + Cover, 4 by 4 ft.

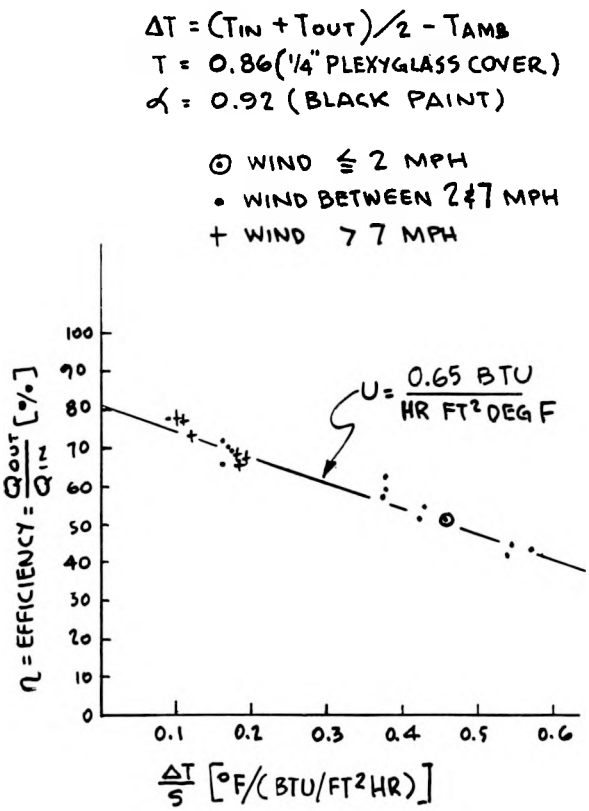


Fig. 6 — CPC 4- by 4-ft. 3:1 Concentrator

DISCUSSION

Comment (Frank DeWinter, Atlas Corporation): Many questions have been raised regarding the large area of reflecting surface required. One 10:1 model shown had a 36-in. height for a 12-in. aperture, for more than 6 ft^2 of area per ft^2 of aperture. Even a 30-40-percent reduction may still leave one with a factor of 4 to 1 or 3 to 1.

Reply (Vaclav J. Sevcik, Argonne National Laboratory): This is correct. One of the drawbacks of this concentrator is that its mirror surface area is larger than for a focusing parabola. This is the price you pay for larger angular acceptance.

Question (Ronald D. Rothchild, Foster-Miller Associates, Inc.): What misalignment can your collector accommodate and operate with, assuming a 10:1 concentration?

Answer: It can accommodate any misalignment smaller than its acceptance angle, which in the case of 10:1 concentration is about 10°.

Question (Unidentified): Since solar energy corresponds to radiation from a 6000° K source, the attainment of high temperature for a given frontal area is limited by environmental heat loss and load. Please explain the advantage you claim in using the concentrator with a Roll-Bond® back surface.

Answer: With the Roll-Bond® receiver, the concentrator bars serve essentially as a mechanical selective surface, basically masking part of the Roll-Bond with mirrors and reducing outward reradiation.

DEVELOPMENT OF A SOLAR HEAT SUPPLY SYSTEM WITH FIXED MIRROR CONCENTRATORS*

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Many potential applications of solar energy require higher temperature collection than is possible with flat plate collectors, so focusing collectors must be used. Since large concentrating surfaces are subject to high wind loadings, it is often advantageous to fix the reflecting surface in a stationary supporting structure and steer a much smaller heat exchanger so that it remains in the focal region. Several fixed concentrator moving heat exchanger systems have been proposed using spherical[1,2] and parabolic[3] concentrators. Large reductions in the cost of mechanical structures and mechanisms can result only if the movable heat collector is much smaller than the reflecting surface, a requirement corresponding to good focus for all incident directions.

Russell[4] proposed a faceted fixed mirror concentrator (FFMC) that has no off-axis aberration and focuses sunlight sharply regardless of the incident light direction. The FFMC is composed of long, narrow flat reflecting elements arranged on a concave cylindrical surface. The angles of the reflecting facets are fixed so that the focal distance is twice the radius of curvature of the cylindrical surface (instead of half) for light normal to the concentrator aperture. The line of focus always lies on the reference cylindrical surface,parallel to the fixed mirrors, so the heat collector can be supported on arms that pivot at the center of the reference cylinder. This greatly simplifies the positioning of the heat exchanger. A simple four-bar linkage can be used to keep the heat exchanger rotated toward the incoming heat flux, so that a terminal concentrator on the heat exchanger can be used to further improve collection efficiency.

Higher temperature heat collection will be advantageous for a variety of solar energy applications related to the supply of heat and cooling to buildings. Rankine cycle air conditioning and total energy systems become increasingly more efficient as the collection temperature is raised above the practical limits of flat plate collectors. Because of the higher efficiency, smaller collector areas are needed and the Rankine cycle equipment becomes less expensive, so focusing collectors may be able to provide lower cost cooling and/or electric power for buildings than would be possible using non-focusing collectors.

Another important application for the FFMC is the supply of industrial process heat. Whereas residential and commercial space heating and cooling accounts for 20% of all U.S. energy consumption, the supply of industrial process heat accounts for 28% of U.S. energy consumption, and 80% of this process heat is used at temperatures of less than 500 °F.[5] About 60% of the process heat is used to produce steam. Since the large majority of process heat applications require higher temperatures than can be effectively provided by flat plate collectors, the FFMC may provide a cost-effective means of meeting this energy need.

In 1972 Russell[6] proposed the FFMC as a possible cost-effective means

*Research supported by NSF/RANN Grant GI-43936

of collecting heat at around 600 °C for central station electric power generation. Williams[7] suggested that concentrators of this general type but of lower concentration ratio may be useful for small scale applications, such as supplying air conditioning and process heat. In November, 1973 a proposal for the development of a solar heat supply system with fixed mirror concentrators was submitted by Georgia Tech and Scientific Atlanta to NSF/RANN in response to program solicitation 73-22. In early 1974 a 61 ft^2 concentrator of unity aspect ratio was built at Georgia Tech under a grant from Scientific Atlanta; this collector is illustrated by Figure 1. NSF Grant GI-43936 was initiated on July 1, 1974, and two related parallel tasks were begun: 1) the collection and analysis of data from the 61 ft^2 concentrator, and 2) the design and construction of a 540 ft^2 concentrator of large aspect ratio. By September, 1974, the first of these tasks had been completed, and the 61 ft^2 concentrator was shown to perform just as the theoretical analysis had predicted.[7] Figure 2 compares the experimental and theoretical concentrator efficiency, Figures 3 and 4 show the theoretical and experimental heat flux profiles. R. K. Bansal, who had just completed his M.S. thesis[8] at Arizona State University on the theoretical analysis of the FFMC has calculated the performance of the 540 ft^2 concentrator under construction at Georgia Tech for various tilt angles. After assembly is complete, the performance of the concentrator will be measured and compared with the results fo the numerical analysis.

At the present time, the prototype FFMC heat supply system, complete with automatic steering and control and 24-hour heat storage, is nearing completion. The reflector array is 7 feet wide and 80 feet long with 28 single-weight rear-surfaced mirror slats symmetrically positioned, each 2.9 inches wide. The subtended angle is 105°, and the collector is oriented east-west and tilted at the latitude angle. The heat exchanger for heating air is constructed to minimize heat loss on the outside and maximize heat absorption on the side facing the reflector. This heat exchanger is designed to heat air to 500 °F with a collection efficiency in excess of 50%. An automatic steering and control system maintains the heat collector in the focal region and operates the blowers and valves so as to supply hot air at about 500 °F upon demand. A NaOH-NaBr eutectic mixture is currently being used to store heat at 500 °F. The reflecting mirrors are supported by aluminum extrusions which are supported by ribs located every 8 feet. Figure 5 illustrates the location of the collector on the roof of the SSTC Building Number 1 at Georgia Tech. Auxiliary system components, such as the heat storage subsystem, are not shown.

It should be emphasized that this collector is being constructed only of components of proven durability as well as an acceptably low cost. This is the reason commercial rear-surfaced mirrors were chosen for the reflecting facets. With a reflectivity of about 85% and a cost of 35¢/ft^2, these mirrors provide a cost-effective concentrating surface. The ribs and supporting extrusions are of aluminum alloy, and the fasteners are of cadmium plated steel. All metallic surfaces are coated to enhance the appearance of the concentrator and increase its durability.

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7. Williams, J.R. and Rollins, J.F., "Experimental Solar Heat Supply System with Fixed Mirror Concentrators", Progress Report No. 1, NSF Grant GI-43936, prepared by the Georgia Institute of Technology, September 1974.
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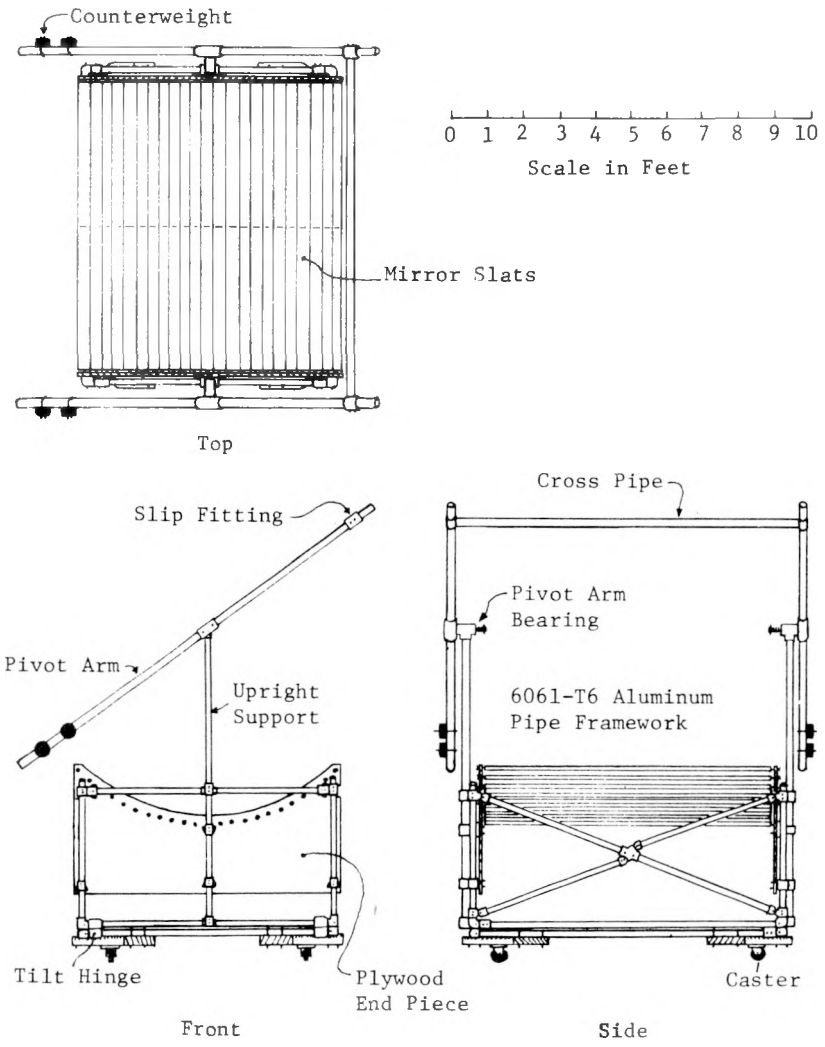


Fig. 1 – 61 ft^2 FFMC at Georgia Tech

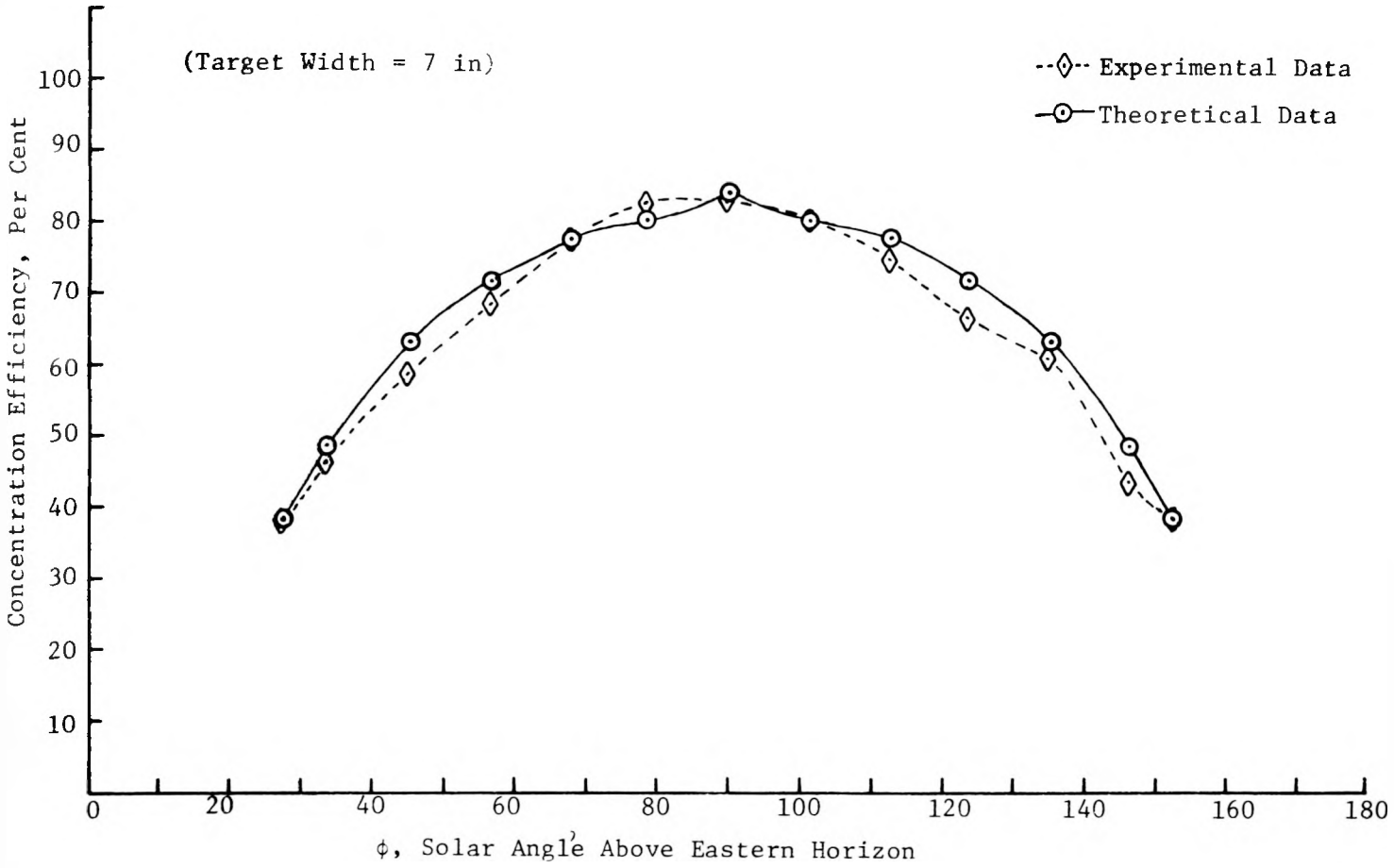


Fig. 2 — Theoretical and Experimental Efficiency of 61 ft^2 FFMC

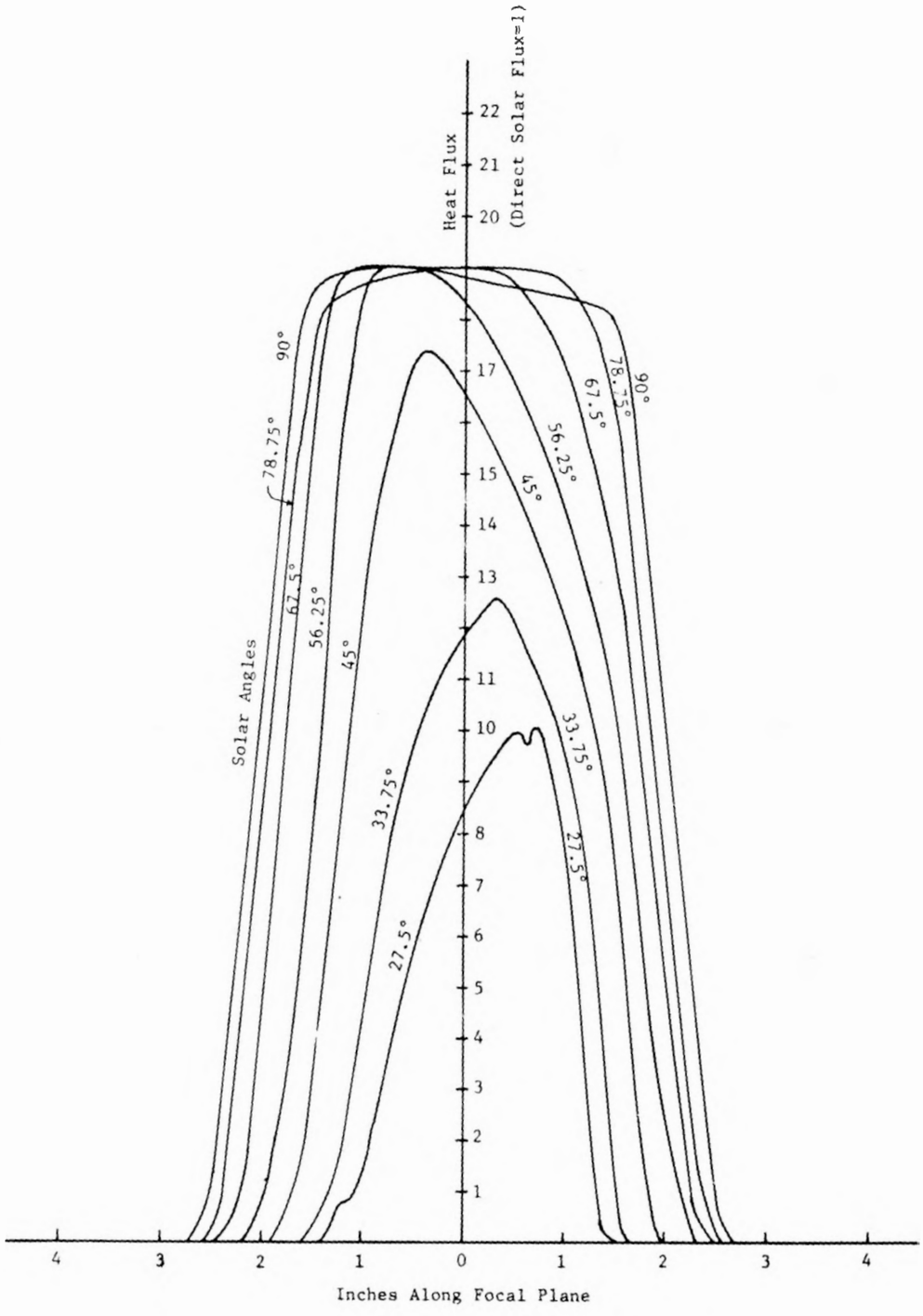


Fig. 3 – Theoretical Heat Flux Profiles at Focal Plane of 61 ft^2 FFMC

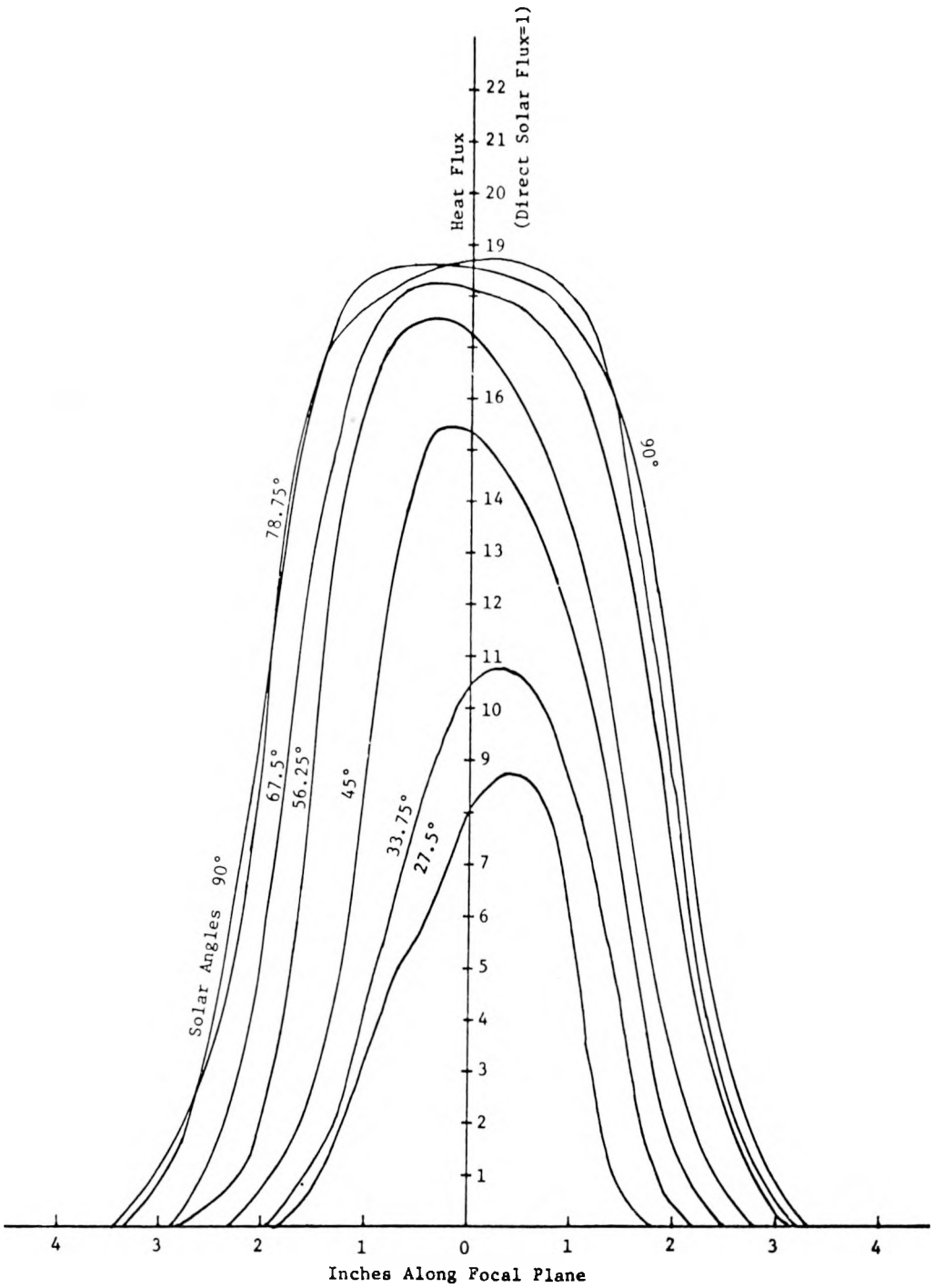


Fig. 4 – Experimental Heat Flux Profiles at Focal Plane of 61 ft^2 FFMC

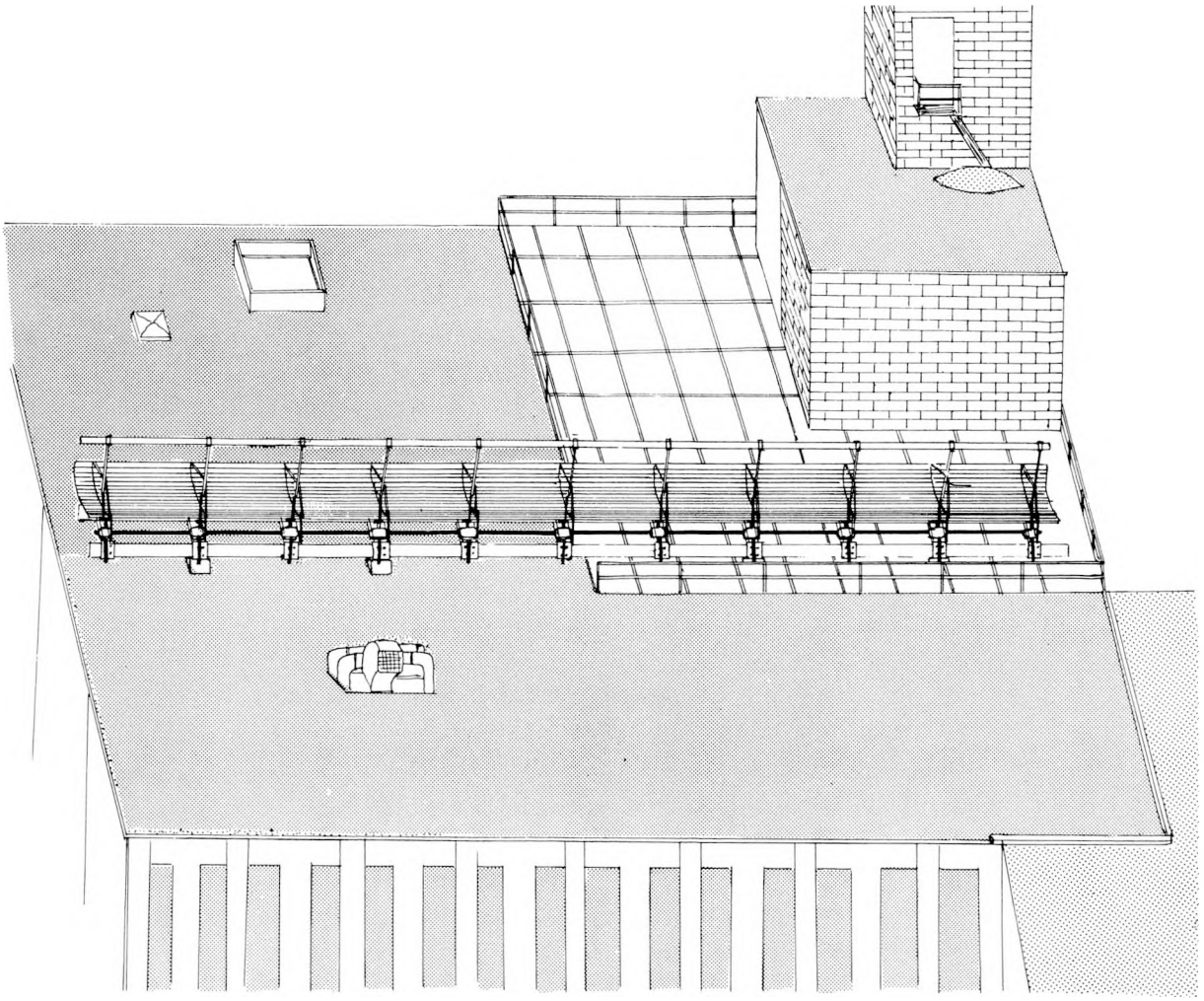


Fig. 5 – 540 ft^2 FFMC on SSTC Bldg. #1 at Georgia Tech

DISCUSSION

Question (Robert K. Swartman, University of Western Ontario): Why did you use circular mirrors for the small concentrator, rather than an array of square mirrors? Square mirrors would completely fill the reflecting area and be easier to manufacture.

Answer (J. Richard Williams, Georgia Institute of Technology): The little concentrator was just a means of producing a solar heat flux for testing paint–the coating we are using on the heat exchanger. These concentrators have been made by numerous people. You simply take an array of 97-cent shaving mirrors, which have a diameter of 6½ in. and a focal length of 3 to 4 ft, and focus them at the same point. The whole set of mirrors cost $35 and was a very cheap way of producing a fairly high solar heat flux because each mirror is concentrating; it is not flat.

Question (Louis Mougin, The Trane Company): Could you comment on the magnitude of the end losses due to reflected radiation that misses the collector tube? How could this be minimized?

Answer: We have the computer programs running to calculate this, and we took a lot of data on the 61-ft model we built. The data were essentially what was predicted. To answer your question, to minimize end losses, make your collector long compared to its width, and reduce your end losses accordingly. Another thing you can do—and this is something we want to do next year—is have an extra heat exchanger on each end, an extra 10 percent that you can cover and uncover, depending on whether that end is illuminated. That way you can pick up additional heat otherwise lost.

Question (Benicio I. Dussan, V, Philadelphia, Pa.): What is the estimated loss in efficiency due to the use of glass mirrors? The glass and reflective substrate will absorb and dissipate heat as the solar rays pass twice through the glass and are reflected. How about using front-faced mirrors?

Answer: Two processes account for a decrease in concentrator efficiency due to the use of rear-surfaced mirrors: absorption of heat in the glass, and reflection losses. Reflection losses are negligible because practically all of the solar energy reflected from the front surface ends up at the heat exchanger anyway. The approximately 10-percent loss due to absorption would not reach the heat exchanger, even if front-surfaced mirrors were used, because of the glass cover plate on the heat exchanger. Thus, front-surfaced mirrors would result in higher costs and decreased durability with little gain in overall collector efficiency.

A SOLAR POWERED STEAM SUPPLEMENT FOR HEATING AND COOLING OF BUILDINGS*

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Many solar energy collectors "work", but they are not necessarily competitive. If solar energy is to have an impact on the energy market, the collector and its associated system must compete successfully with other energy sources. This is the last barrier.

Where is the solar energy competition weakest? in the northeastern part of the U.S., in the populated regions from Boston to Washington. In this region, coal cannot be used because of its sulfur content, gas does not exist for new customers, electric power for industrial users has reached $8.20 per million Btu, thermal energy from oil costs $3.30 per million Btu and nuclear power installed in this populated area has raised many serious questions. This region is ripe for a new energy source. If solar energy is adapted properly to the market, the competitive barrier can be penetrated, not in 1985, but in the next few years. The sun is in the southwest, but the market is in the northeast.

To meet this potential market, we propose solar steam generated by the collector shown in Fig. 1 and used as an energy supplement.

This "power tower" type of solar energy collector has several economic and performance advantages over other possible collectors. These are:

1. Good Thermal Efficiency - The very high concentration factors easily possible with this type of collector produce ultimate temperatures far above those at which the energy is utilized. This results in very high thermal efficiency; in this case above 90% (thermal output/energy incident on the boiler).

2. Energy Collection - Energy is centrally collected while in radiant form, thus eliminating a high temperature collection system with possible secondary fluids and heat exchangers.

3. Supplemental Use - In order to utilize solar energy most economically, energy storage has been eliminated. This eliminates the energy losses going in and out of storage and the cost of the storage element. Storage may be added later, if justified.

4. Cooling - The "power tower" type energy collector easily produces steam at the temperature necessary to power existing absorption-type air conditioning. This couples, in an effective way, the summertime air conditioning load to the incoming solar radiation providing good efficient utilization of the solar energy collector during this season.

   Figure 2 shows performance characteristics of this type of air conditioning equipment. The advantage of steam near 350° F is overwhelmingly demonstrated. By no other means can coefficients of performance near 0.9 be achieved. As the coefficient of performance of the air

*Work performed under the auspices of the U.S. Atomic Energy Commission.

conditioner increases the collector area required for a given task is reduced resulting in major cost savings.

Can we make a "power tower" type collector cheap enough to be competitive? This is an engineering question; a question of production economics. But, this is where modern technology can have its greatest impact. This type collector requires less material per unit area of collector, is more sophisticated and has a higher technology content than some types of stationary collectors.

The cost of this collector system is dominated by the cost of the reflector and its transport.

The NSF Solar Thermal Program has studied large-scale "power tower" type collectors designed to generate electric power on an economic scale. Towers of 1000 or more feet high collecting radiant energy from a square mile have been considered. The costs of reflectors designed for such systems are estimated to be near \$4 to \$5/ft^2. The reflector needed for a small "power tower" is greatly simplified from those needed in the larger systems. The aiming accuracy can be relaxed from a few milliradians to over 30 milliradians with corresponding relaxations of the flatness and mount rigidity tolerances. These changes have far-reaching engineering consequences resulting in major cost reductions in the surface and support mechanism. Our cost studies indicate that reflectors of this design can be mass produced for \$2.50/ft^2.

Figure 3 shows this reflector in different positions. Note the face down "park" position planned for use at night and during inclement weather. This mechanism is powered by two 1/6 hp motors. Several fabrication techniques are under study for the reflectors. These include, skin and frame, bonded stampings and honeycomb with skin. Further study and modeling are required to identify the most economical method.

The reflector must withstand wind forces. For gusts above 30 mph, the image will be allowed to go off target and for wind speeds above 50 mph the reflector will be lowered into its "park" position.

Position control is accomplished with a small (desk top type) computer and simple printed circuit card interface.

The boiler shown schematically in Fig. 4 is a simple modification of a conventional tube type steam boiler. Reflectors have been added to concentrate the radiant energy on the tubes and to provide some wind screening. No glazing is planned because the reflection loss at the air-glass interface is greater than the thermal loss from the boiler tubes due to wind.

In order to make a cost analysis, a system employing 29 reflectors and one boiler was considered. Table I summarizes the results.

Clearly, in this example there is a cost saving for the customer and a profit for the user, two conditions necessary for commercial acceptance.

In summary, we believe that solar energy delivered in the form of steam from a "power tower" type collector and used as an energy supplement can challenge the dominance of fossil fuels in the northeastern part of the

United States for the heating and cooling loads of buildings, and by doing so, will break the last barrier to the widespread use of solar energy.

TABLE I
COST ANALYSIS SUMMARY

Savings Per Year		Cost Per Year-Solar	
Collective Area	11 600 ft^2	Reflector Cost	$29 000
Solar input/ft^2/yr at ⊥	6.5 × 10^5 Btu	Controls	1 500
System efficiency	80 %	Boiler	6 000
Geometry factor	87 %	Tower	6 000
Energy collected/yr	5.2 × 10^9 Btu	Installation and Tests	8 000
			$50 500
Fuel saved	47 300 gal	Profit & Overhead @ 30%	15 150
ANNUAL SAVINGS (at today's prices)	$18 900		$65 650
		Amortized 12% for 10 yr	$11 383
		Maintenance	2 000
		TOTAL ANNUAL COST	$13 383

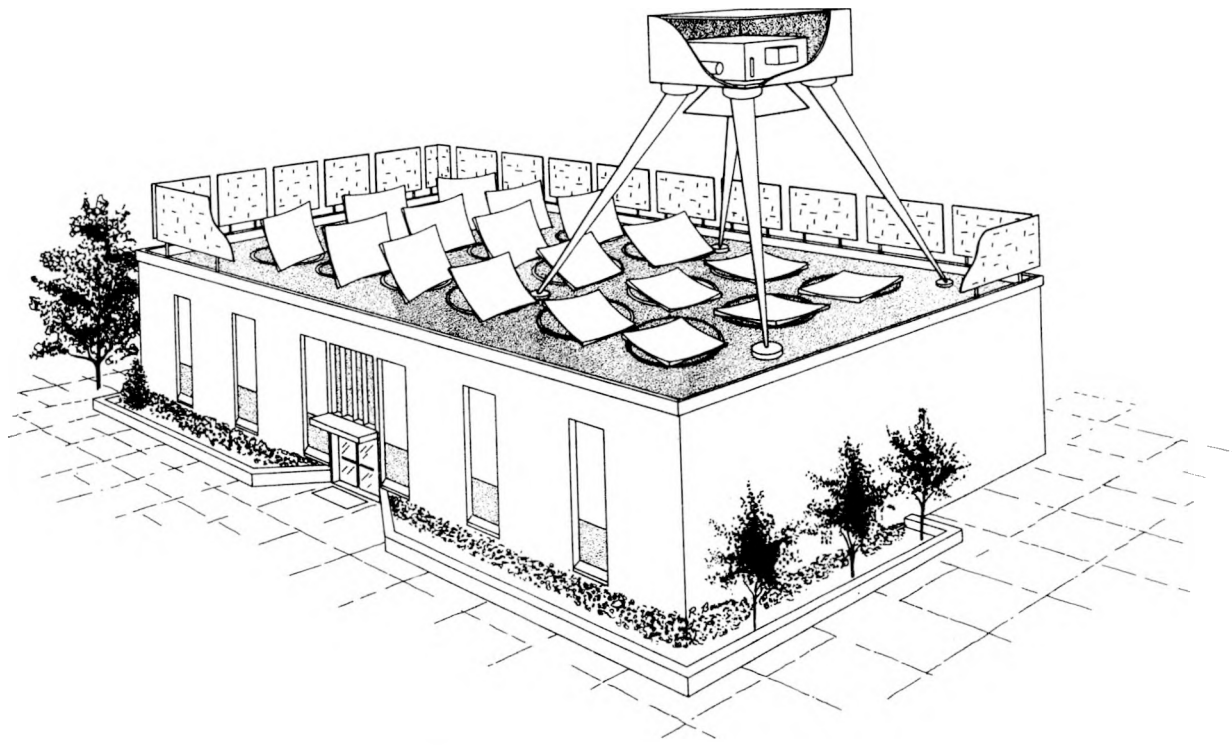


Fig. 1 – Small-Scale Power Tower Type Solar Energy Collector by Artist Rip Bowman

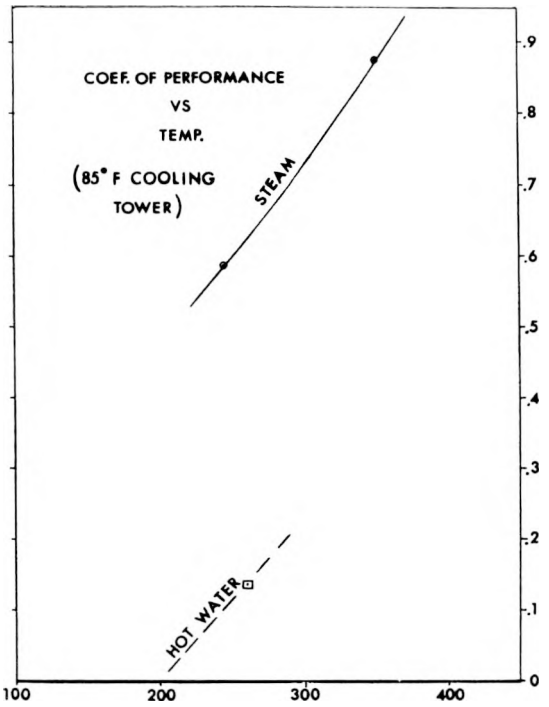


Fig. 2 – Coefficient of Performance (C.O.P.) Characteristics for Commercially Available Absorption-Type Air Conditioning vs. Temperature

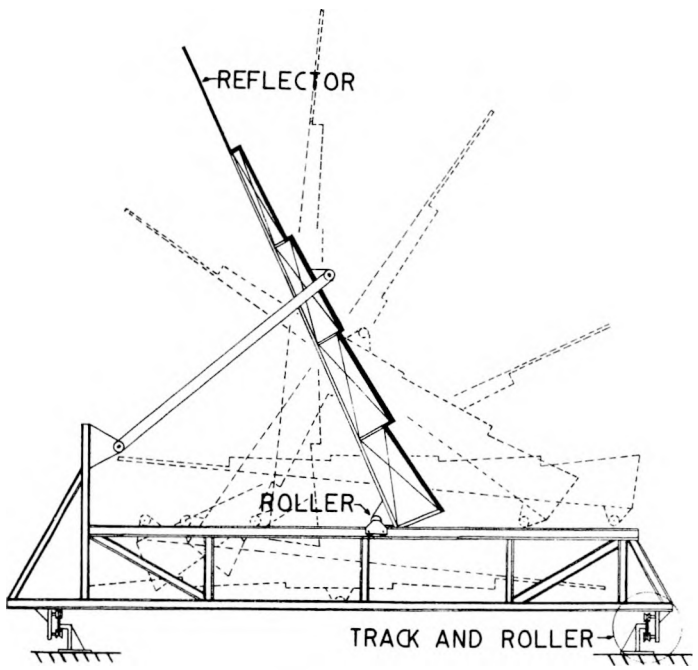


Fig. 3 – Faceted Reflector and Motion Transport

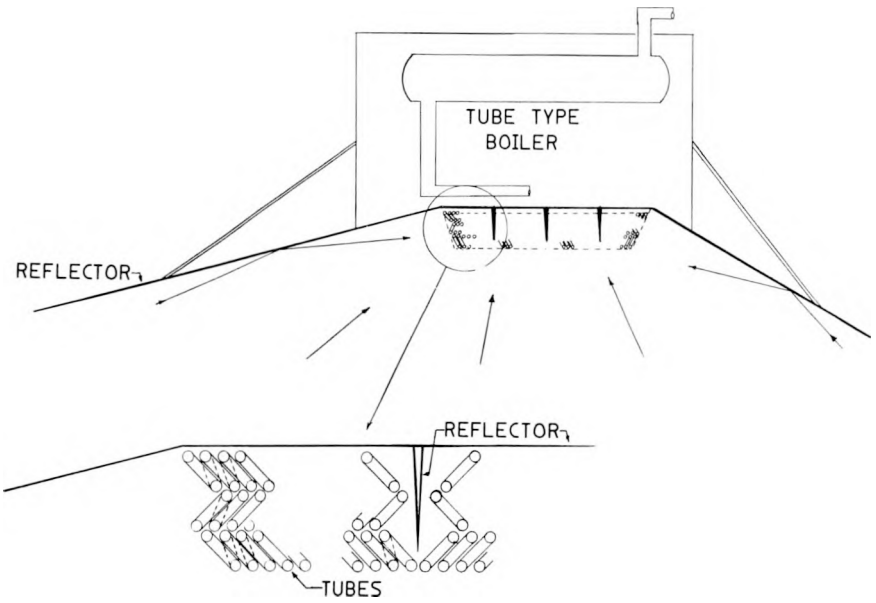


Fig. 4 — Tube-Type Steam Boiler Modified With Concentrating-Type Reflectors

DISCUSSION

Comment (Frank DeWinter, Atlas Corporation): Before presenting questions to Mr. Cottingham on the Baum-type tower, let me mention that this concept was first examined in depth by Dr. Baum in Russia and that he also used the track, with railway cars going around the tower. Professor Hottel and Professor Sarofim at MIT discussed this with him at the Paris conference. They went through a complete economic study, in which they concluded that there were only two places in the United States where—in the early 1960's—the system made sense.

Response (James G. Cottingham, Brookhaven National Laboratory): Since the Russian work, energy costing has changed and brought the Baum concept back to life again.

Question (Charles J. Swet, Community Technology, Inc.): Do your figures on solar input per year used in costing allow for percent direct radiation?

Answer: The solar input per year used in the costing calculation includes only the direct insolation component, since the diffuse component cannot be focused. Good measurements of the direct components of insolation do not exist. The value used was obtained by calculations from other measurements using several estimating techniques.

Question (Salem O. Kabawi, Libyan Atomic Energy Commission): Referring to the costs you mention, using tower concentrators, do you think that the costs will be increased in dusty-weather countries, and do you think this system is effective in such weather? In countries like Libya, for example, where the weather is always sandy or dusty, the grains of sand will collect on the concentrator and decrease the efficiency of the system.

Answer: The costing calculations presented were based on the best estimate of direct insolation for Long Island, N.Y., and must be reexamined for other locations. I would expect dust to impair collection efficiency by 8 to 15 percent. Cleansing by rain should be very effective. I would expect this loss to be more than offset by the increased insolation to be found in Libya.

52,089

COST EFFECTIVE FOCUSING COLLECTOR FOR SOLAR HEATING AND COOLING

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The basic design concept is for a roof-top solar concentrator composed of a fixed roof of somewhat cylindrical shape which is also the mirror of the concentrator (see Figure 1). A collector of 1/8 to 1/10 the area of the mirror is moved at intervals daily to be in the approximate focus of the mirror concentrator. This system is optimized in angular setting for the heating and cooling requirements of a building and its latitude. Many combinations and concepts have been investigated.

Figure 2 shows a typical 100-square-foot model. The collector bar is out of scale in this picture since it consists of an insulated box with 3 inches of insulation around the top and sides and the insulation cannot be scaled. A larger model would utilize the same depth of concentrator only enlarging the width in ratio with the mirror area.

Shown in Figure 3 is a model of the 100,000-square foot building designed for the location of Twenty-Nine Palms, California, employing the solar concentrator concept. The roof material is designed as glass with a silvered second surface protected by copper, tin and lead, plus an epoxy coating. This appears optimum from a cost, performance and life standpoint. The shading coefficient reduces air-conditioning from 233 tons to 128 tons.

Many buildings are now built utilizing various insolating/reflecting glass combinations on an inclined area. None of these are used intentionally as solar collectors. Shown in Figure 4 is a building in the Southwest, one whole side of which is of reflective glass.

With very little additional cost to the side of the building, the design shown in Figure 5 would utilize the reflective window area as a solar collector system concentrating the energy on the collector bar.

In areas of the South and Southwest it appears that the high temperature capability of this concentrator would allow the generation of electrical power required for some of the school's operation; then, by cascading the waste heat to run an absorption air-conditioner at 200°F, provide services hot water and heating, and with a chiller water storage tank utilize the chiller water generated by the absorption unit for cooling. This would provide a total energy concept for areas where sunshine is plentiful (see Figure 6).

On the flat plate collector system we had discussed the simplified basic principles of solar fuel cost which equals the total added cost of building and equipment plus amortization and maintenance divided by the energy collected. This can be broken down as shown in Figure 7.

The solar energy transmitted and absorbed minus the energy lost over the solar energy available is a definition of efficiency.

Figure 8 illustrates the various efficiencies and losses used to compare the performance of flat plate collectors and solar concentrators for a specific set of conditions.

Figure 9 shows how the efficiency comparison varies with the variation in instantaneous insolation.

Again, to illustrate a point, in Figure 10 the insolation is shown for a typical day where the peak is about 200 Btu per square foot. In the case of the concentrator the utilization factor is 82%, while the utilization factor with the flat plate is only 21%.

Figure 11 shows the efficiency (the percent of daily insolation collected) for an 8 to 1 concentrator and a flat plate. This data is for June and 40^{O}N latitude. The upper two lines represent efficiencies using two different methods for calculating diffuse and direct energy.

Let us look at a cost comparison of the two systems, assuming a 100,000 square-foot area to be heated and cooled and a 50,000 square foot collector (Figure 12).

In summary, using our cost factors calculated in Figure 12, and a study of the energy collected over the year for each system, we come up with a cost per million Btu of about $8 for the flat plate collectors and under $2 for the concentrator (Figure 13).

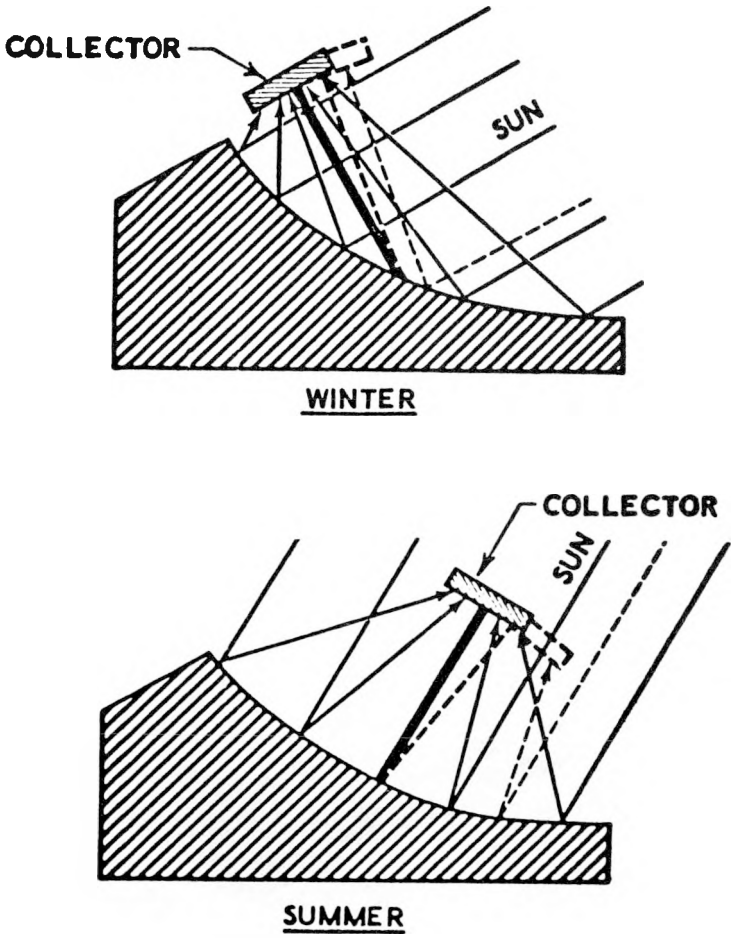


Fig. 1 — Basic Design Concept for a Rooftop Concentrator

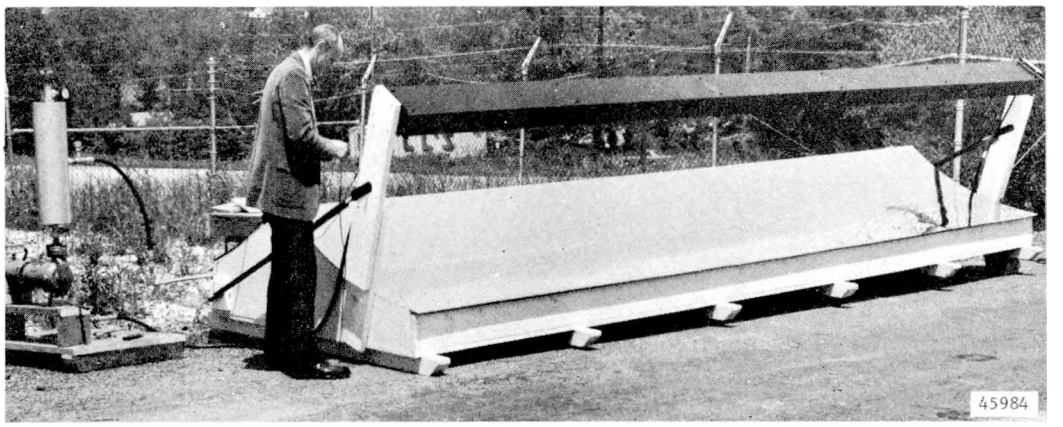


Fig. 2 – Focusing Collector Model with 100-sq.-ft. Collecting Area

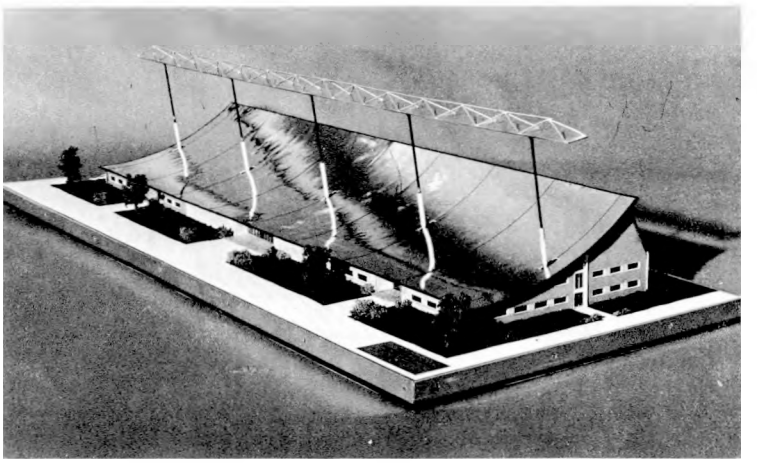


Fig. 3 – Model of a Building for Southern California Employing a Concentrating Collector

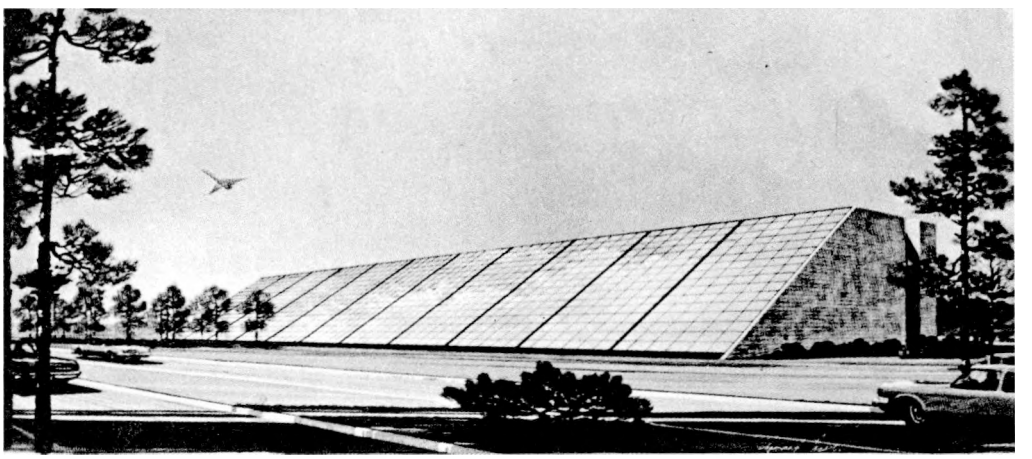


Fig. 4 – Model of a Building in the Southwest U.S. with Reflective Glass Wall

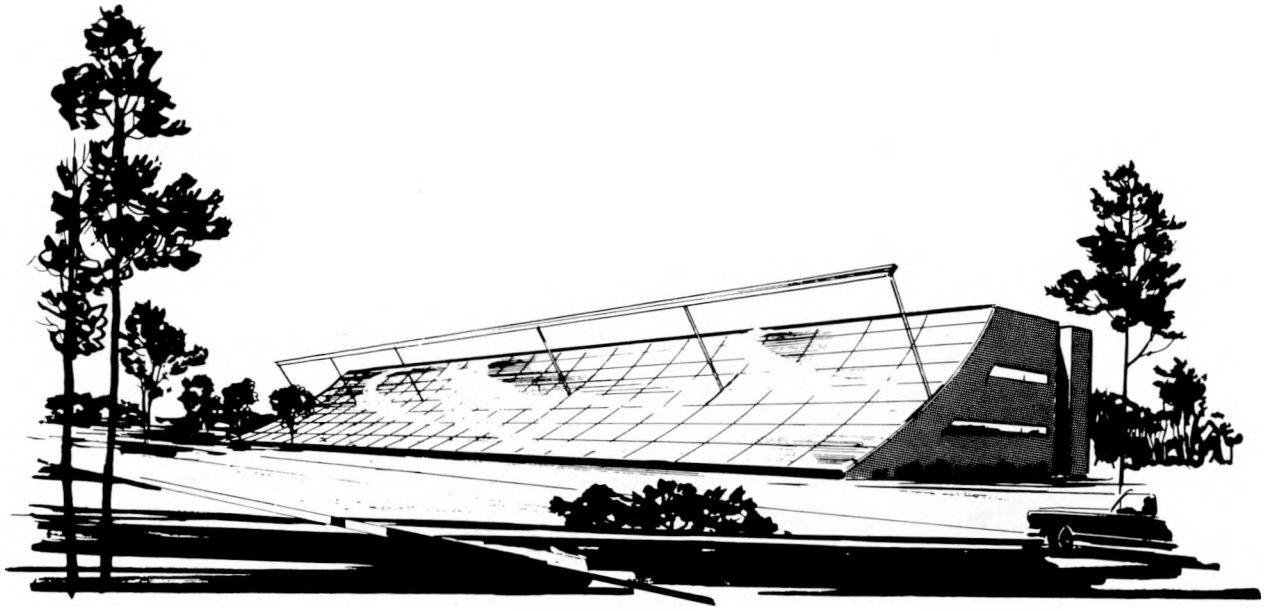


Fig. 5 — Modification to Building in Figure 4 to Utilize Concentrating Collector

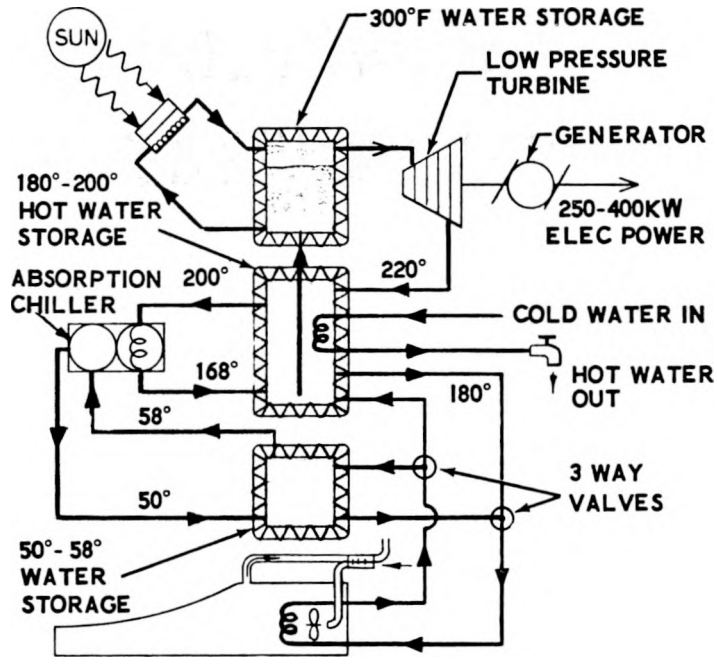


Fig. 6 — Total Solar Energy System for a School, Including Heating, Cooling, and Electrical Power Generation. (All Temperatures are Shown in Degrees Fahrenheit.)

$$\text{COST OF "SOLAR FUEL"} = \frac{\text{COST (DOLLARS)}}{\text{ENERGY COLLECTED (BTU)}}$$

(1)

$$\frac{\text{AMORTIZATION OF ADDED COST - BLDG. \& EQUIP. + MAINT.}}{\text{BTU AVAILABLE} \times \text{EFFICIENCY} \times \text{UTILIZATION FACTOR} \times \text{LIFE}}$$

(2) (3) (4) (5)

(1) PRIMARILY COST OF SOLAR COLLECTOR - PLUMBING, STORAGE AND CONTROLS.

(2) BTU AVAILABLE, INSOLATION - DEPENDS ON LOCALITY.

(3) EFFICIENCY - DEPENDS PRIMARILY ON TYPE OF COLLECTOR AND TEMPERATURE OF COLLECTOR ABOVE AMBIENT TEMP.

(4) UTILIZATION FACTOR - DEPENDS ON LOCALITY, ANGULAR ATTITUDE, EFFICIENCY AND TEMPERATURE OF COLLECTOR.

(5) LIFE - DEPENDS ON DESIGN AND MATERIALS.

SOLAR EFFICIENCY

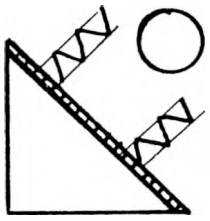
$$\eta = \frac{\text{SOLAR ENERGY COLLECTED}}{\text{SOLAR ENERGY AVAILABLE}}$$

$$\eta = \frac{\text{SOLAR ENERGY TRANSMITTED-ENERGY LOST}}{\text{SOLAR ENERGY AVAILABLE}}$$

Fig. 7 — Simplified Basic Principles of Solar Heating/Cooling Economics

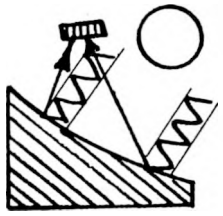
TRANSMISSION EFFICIENCY

FLAT PLATE COLLECTORS



Diffuse Radiation Effect	= .98
Dust Losses	= .98
30^{o} Angle Effective Shade	= .93
Transmission Absorption (2 glass panes)	= .755
N_T = .98 x .98 x .93 x .755	= .675

CONCENTRATORS



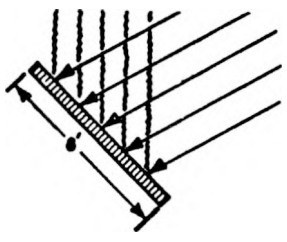
Diffuse Radiation Loss	= .85
Reflectivity Loss	= .86
Dust Losses	= .96
30^{o} Angle Effect Shade	= .93
Transmission Absorption (1 glass pane)	= .85
N_T = .85 x .86 x .96 x .93 x .85	= .559

CONDITIONS

COLLECTION TEMPERATURE	= 200^{o}F
AMBIENT TEMPERATURE	= 80^{o}F
ΔT	= 120^{o}F
INSOLATION	= 200 BTU/FT^2
AREA OF COLLECTOR	= 1/8 OF REFLECTOR

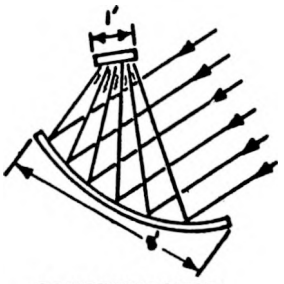
FLAT PLATE		CONCENTRATOR	
TRANS. COEF.	= .68	REFLECT. TRANS.	= .554
HEAT LOSS COEF.	= .38	HEAT LOSS COEF. (no inner convection)	= .33/8
TOTAL EFF.	= .3	TOTAL EFF.	= .513

LOSSES = .38



FLAT PLATE
TOTAL EFF. .3

LOSSES = .33/8



CONCENTRATOR
TOTAL EFF. .513

Fig. 8 — Comparison Between Flat Plate and Concentrating Collectors

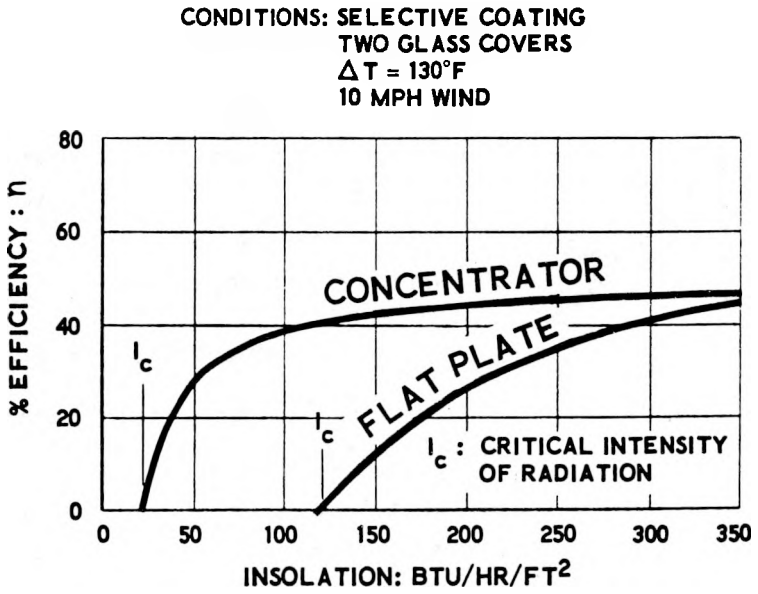


Fig. 9 — Effect of Insolation on Efficiency

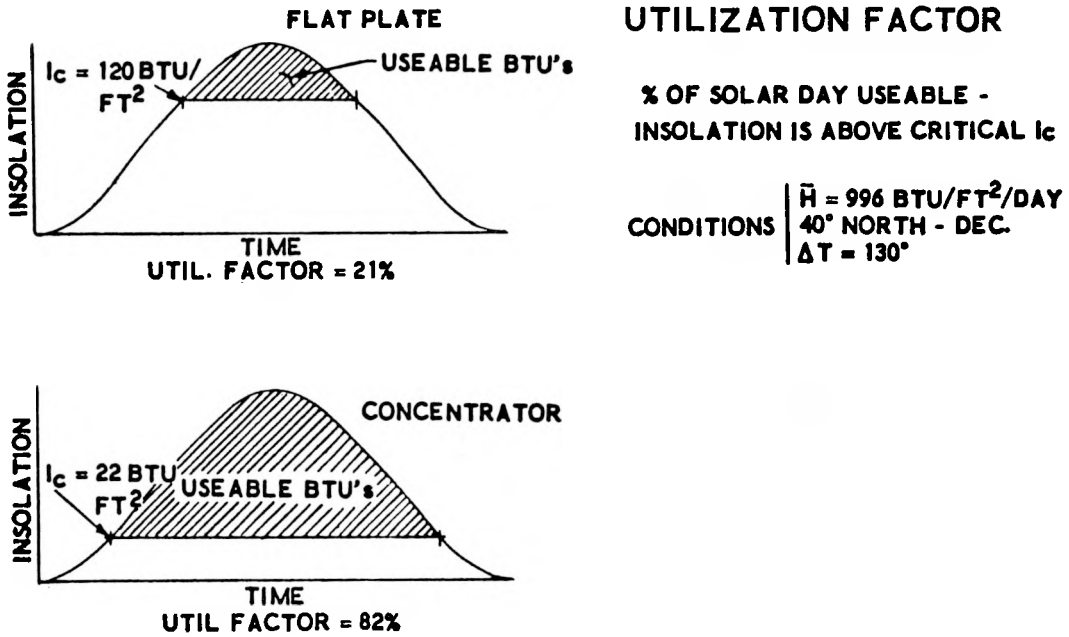


Fig. 10 — Utilization Factor Comparison for Flat Plate and Focusing Collectors

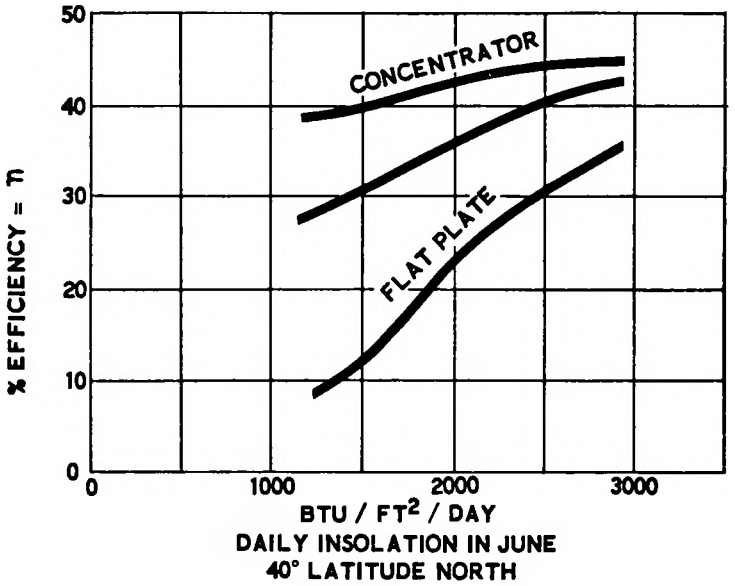


Fig. 11 – Collector Efficiency vs. Daily Insolation

COST COMPARISON
100,000 FT^2 SCHOOL
50,000 FT^2 COLLECTOR

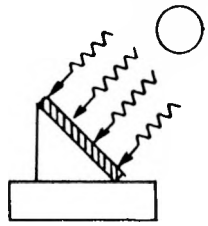
	Flat Plate		Concentrator	
	Cost ($)	Cost/Ft^2	Cost($)	Cost/Ft^2
Collector	280,000	5.60	71,500	1.40
Reflector	--	--	17,500	.35
Collector Assembly	75,000	1.50	15,000	.30
Elec. Control Unit	5,000	.10	7,500	.15
Mech. Control Unit	--	--	20,000	.40
Pumping Unit	3,000	.06	3,000	.06
Water Storage	50,000	1.00	50,000	1.00
Installation	100,000	2.00	50,000	1.00
Total	513,000	10.26	234,500	4.66

Fig. 12 – Cost Figures for Collector Comparison

RELATIVE COST OF SOLAR FUEL
WASHINGTON, D.C.

$$\frac{\$}{BTU} = \frac{\text{COST OF SYSTEM + 20 YEAR LIFE (@8\%) + MAINT.}}{\text{BTU AVAIL. x TRANS. x UTIL. FACTOR x LIFE EFF.}}$$

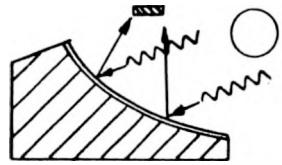
$$\frac{\$}{BTU} = \frac{\$10.26/\text{SQ FT (2)} + .02(20)}{595{,}000 \times .675 \times .331 \times 20 \text{ YR.}}$$



$$\frac{\$}{BTU} = \frac{\$7.87}{1{,}000{,}000 \text{ BTU's}}$$

FLAT PLATE COLLECTOR

$$\frac{\$}{BTU} = \frac{\$4.66/\text{SQ FT (2)} + .02(20)}{595{,}000 \times .554 \times .843 \times 20 \text{ YR.}}$$



$$\frac{\$}{BTU} = \frac{\$1.75}{1{,}000{,}000 \text{ BTU's}}$$

CONCENTRATOR

RELATIVE COST OF SOLAR FUEL			
	BALTIMORE	MIAMI	29 PALMS
BTU'S AVAIL.	595,000	670,000	770,000
COST	$\frac{\$1.75}{10^6 \text{ BTU}}$	$\frac{\$1.45}{10^6 \text{ BTU}}$	$\frac{\$1.13}{10^6 \text{ BTU}}$

Fig. 13 — Results of Collector Cost Comparison

DISCUSSION

Question (Leslie R. Wright, Institute of Gas Technology): What happens to efficiency and cost when the collector becomes pitted by continuous blowing sand and sand storms, which are common to the Mojave Desert region?

Answer (Irwin R. Barr, AAI Corporation): The glass is much less affected than certain plastics. Studies of aircraft windshields and plastic canopies on airplanes stored in the desert for many years have shown only small transmission losses on the exposed surfaces.

Question (Paul A. LaViolette, Resource Planning Associates): Why was the reflective surface that you used cheaper than aluminized plastic?

Answer: Aluminized plastic using thick aluminized Mylar is specular on a reasonably smooth substrate, but does not have the projected 20-year life. Teflon-covered thin aluminized Mylar costs double to triple that of the glass mirror and is not specular unless cast against a very smooth male mold. This raised the cost even higher. Aluminum with anodic coatings cost four times that of the glass and the predicted life was much shorter.

Question (Harold R. Dessau, Electra Sol Labs, Inc.): You state that a concentrator is more efficient than a flat plate collector at low levels of insolation. However, is it not true that low levels of insolation are usually associated with haze, when the insolation is more diffuse? In such a case, would it not be that low levels are primarily diffuse radiation that cannot be effectively concentrated?

Answer: Please note figure 9, "Efficiency vs. Insolation." At ΔT's of 130° F and an insolation of 120 Btu/hr/ft^2, the efficiency of a flat-plate collector is 0. At this point the efficiency of a concentrator is shown as 40 percent. Measurements taken at average readings of 120 Btu/hr/ft^2 insolation with the diffuse averaging 45 percent of total radiation show efficiencies of over 30 percent. If the ΔT (collection to ambient) was less than 50°, then the efficiency of the flat plate would be better than the concentrator at this insolation.

Comment (Unidentified): The assumption of the heat losses from the solar concentrator being a function of the ratio of its area to that of a flat collector is erroneous in view of the significant difference in temperatures involved.

Response: One of the major points of this paper was a comparison of flat plate and focusing collectors at the *same* collector water temperature, so there is no significant difference in the temperatures involved. The comparison illustrated in figure 8 is a ΔT of 120° F (collection temperature above ambient). This would be the same for a water temperature of 120° F with ambient air temperature at 0° F, or 200° F with air temperatures at 80° F. While it is apparent that you can obtain much higher temperatures with a concentrator, a significant point is its efficiency advantages at the moderately high collection temperatures needed to run present-day absorption air conditioners.

"MODELING AND CONSTRUCTION OF THE STATIONARY REFLECTOR/ TRACKING ABSORBER SOLAR COLLECTOR"

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Boulder, Colorado 80302

Objective

It is the purpose of the development effort described herein to bring to the functional level both a mathematical and physical prototype of the Stationary Reflector/Tracking Absorber (SRTA) solar collector.* This collector concept is due to Dr. W. Gene Steward (1) of ECS, Inc. and consists of a spatially fixed, internally reflectorized segment of a sphere and a sun-tracking cylindrical absorber. It differs fundamentally from earlier concentrators in that the reflector need not move to track the sun; only the small absorber pipe moves in a planar trajectory to track the virtual, diurnal motion of the sun (see Fig. 1). The development program whose results are described herein has been underway for about one year under private funding of Steward and the author.

Development Plan

The staged program of practical realization of the SRTA concept includes the following steps:

1) Prepare computerized model of SRTA collector.

2) Prepare physical model of SRTA collector.

3) Build full scale system integrated into a house.

The computerized model has been completed and is described elsewhere by Kreider and Steward (2). Steward has completed a two-foot diameter model of the SRTA collector and has also nearly completed construction of a full-scale collector on his private home.

Mathematical Model Results

The SRTA collector can be used to produce hot water or steam. Typical temperature and heat flux profiles along the absorber are shown in Figure 2, in which X is measured outward from the geometric center of the spherical segment, R_o the radius, T_i, T_o and T_a the collector inlet, outlet fluid, and ambient temperatures, respectively, ρ_m the mirror reflectance, CR the concentration ratio, $\alpha_{a,uv}$ the absorber

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*Patent applied for.

absorptance, $\varepsilon_{a,ir}$ the absorber emittance, and $\dot{m}$ the fluid rate. Liquid heating at large X/R_o is followed by constant temperature boiling, followed by superheating at smaller X/R_o.

Collector efficiency primarily depends upon concentration ratio (CR), fluid flow rate ($\dot{m}$), insolation (G_s), and absorber surface properties ($\alpha_{a,uv}$, $\varepsilon_{a,ir}$) for a given set of ambient conditions. Figures 3 and 4 show the effects of these several paramters upon efficiency η (based on beam radiation).

Status of Physical Model and Full Scale System

Data collection has begun on the physical model but is not sufficiently complete to report at this writing, although the model-predicted performance and data seem to agree.

The full scale system constructed by Steward was fabricated by spraying polyurethane foam on a spherically shaped, expanded metal substrate. The substrate is then shaped to a more precise spherical surface and the reflecting medium applied. The reflectant will be supplied by a large U.S. aluminum company.

Relation to U.S. Solar Heating and Cooling Effort and Potential Users

Preliminary economic analyses indicate that the SRTA collector can deliver energy more inexpensively than can planar collectors in sunny regions of the U.S.--the South, the Four Corners States, and Southern California and Nevada. It is in this same region of the country that the SRTA unit has a distinct economic advantage during the air conditioning season when steam generated by this collector can be used to operate an absorption air conditioner at a COP $\sim$ 0.85 compared to the COP $\simeq$ .55 from flat plate fired units. This is a result of the higher outlet temperature of a concentrator and its thermodynamic consequences.

A SRTA collector bank consisting of 100 ft^2 units injection molded from polyurethane foam can be mounted on the roof of an existing building or that of a new building without special provision since each assembly would weigh less than 100 pounds. Such units can also be made part of the wall of a building, serving the dual purpose of solar collector and insulating layer. In addition to building conditioning, the SRTA collector shows economic promise when considered for steam generation for a peaking electric generator facility.

References

1. Steward, W. G. 1973 "A Concentrating Solar Energy System Employing a Stationary Spherical Mirror and a Movable Collector," Proceedings of the Solar Heating and Cooling for Buildings Workshop, Washington, D.C.: U.S. Government Printing Office.

2. Kreider, J. F. and Steward, W. G. 1974 "The Stationare Reflector/Tracking Absorber Solar Concentrator," USISES Annual Meeting, August 21-23, Fort Collins, Colorado.

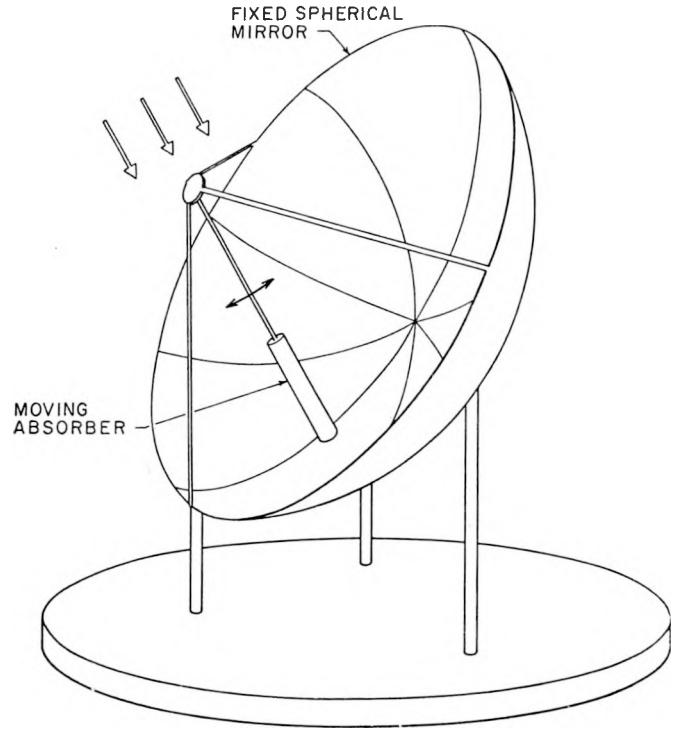


Fig. 1 – Schematic Diagram of SRTA Collector

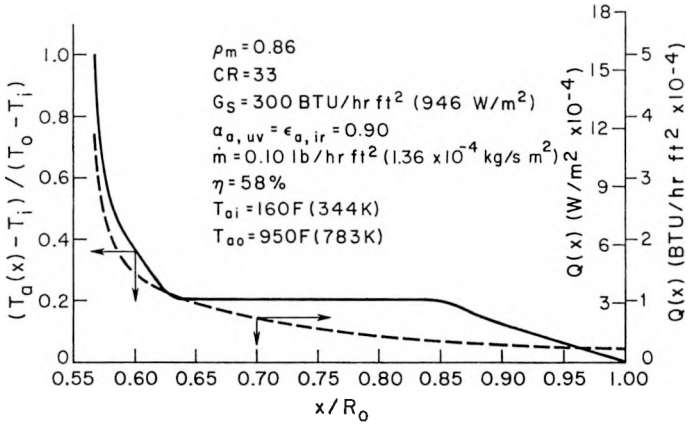


Fig. 2 — Temperature and Heat Flux Profiles along the SRTA Absorber

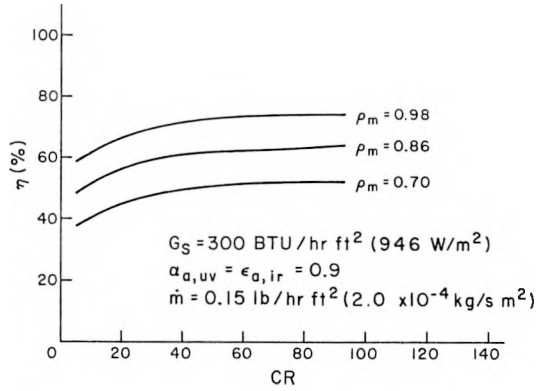


Fig. 3 — Effect of Mirror Reflectance on SRTA Collector Performance

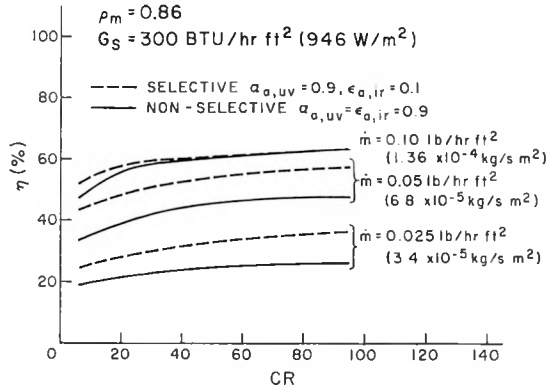


Fig. 4 — Effect of Absorber Surface Selectivity and Fluid Flow Rate on SRTA Collector Performance

DISCUSSION

Question (Benicio I. Dussan, V, Philadelphia, Pa.): What percentage of the solar energy impinging on the reflector is reflected upon the absorber? Is this taken into account for the efficiency?

Answer (Jan F. Kreider, Environmental Consulting Services): For a concentration ratio below 50 and a combined surface-plus-steering error of 10 milliradians, all the direct component of radiation entering the aperture of an SRTA concentrator will impinge upon the absorber cylinder.

52,091

ECONOMIC CONSIDERATIONS FOR FOCUSING COLLECTORS

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Consulting Engineer
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Boulder, Colorado 80302

Objective: The objective of this presentation is to outline criteria to be used in comparing the cost of useful energy delivered by different types of solar collectors, to summarize available cost projections for SRTA focusing collectors, and to present preliminary results on the performance of a Stationary Reflector/Tracking Absorber (SRTA) solar energy collector.

Cost Criteria: Economic factors of significance in determining the cost of solar energy are discussed in Refs. 1 and 2. Economic evaluations of the cost of solar energy should be based on the useful energy delivered per net dollar investment, not on the cost of the collector alone. There is no single solar energy collector which is superior to others, and in each case the total solar collection system should be engineered to fit the job (1). Table I summarizes the most significant features of current types of solar energy collectors (Refs. 3-9), i.e., flat plate, intermediate concentration, high concentration with tracking reflector, high concentration with stationary reflector.

If a complete standby system is required and the saving in fuel cost by means of a given solar energy collector is the main evaluation criterion, this saving in dollars per year, S, is given by

$$S = A_c C_e \int_{\text{year}} Q_s(\tau)\eta(\tau)\, d\tau - m$$

where A_c is the effective surface area of the collector (actual surface area for a flat plate, reflector aperture area for a focusing type),
C_e is the cost of the energy replaced by the delivered solar energy,
$Q_s(\tau)$ is the solar insolation during the year,
$\eta(\tau)$ is the efficiency of collector (ratio of heat delivered to solar insolation) during the year at any given condition,
τ is time (integrated over the year), and
m is the cost of maintenance over the year.

On the other hand, the cost of the solar energy actually delivered, E_s, is determined by the initial investment in the solar collector and storage system, the interest rate at which

the investment is repaid, and the time period of amortization (see Refs. 1 and 2). On a national scale also the amount of energy required to produce the solar collector system compared to the total energy delivered during its lifetime and the requirements of scarce materials, e.g., copper or anti-freeze, for construction and operation should be considered.

It is apparent that to obtain maxiumum return on the investment and to achieve a large saving in conventional fuel consumption:

1. the cost of the collection system per unit aperture area should be low;
2. the efficiency of the collector should be high;
3. the total time during a year when the collector delivers useful energy should be large; and
4. the cost of maintenance should be low.

Additional considerations are that with a higher outlet temperature of the working fluid (within certain limits), the thermal storage energy is cheaper and the possibility of using the collector over a longer period during the year is greater, e.g., solar energy can be used for generating electric power when the solar energy collected is not used for heating or cooling a building. In such a scheme, even a relatively low electric power generation efficiency is acceptable.

Fig. 1 compares schematically the construction of a double-glazed flat plate collector (FPC) with that of a concentrating surface of an SRTA collector, and Table II summarizes the advantages and disadvantages of both types of collectors. The possibility of reducing the cost of a good flat plate collector below $6 per square foot of surface area is unlikely because the cost of materials of construction is high. On the other hand, the material cost of a reflecting surface is considerably lower than for a flat plate collector with no concentration. Since the collector surface of a high concentration system such as SRTA or a cylindrical parabolic concentrator (CPC) is only 3 percent of the aperture area, the system cost depends principally on the reflector, provided the entire reflector need not move to track the sun with a high cost tracking mechanism. For a stationary reflector/tracking absorber the cost of the absorber and tracking system is a small part of the total system, based on the experience gained by the author and his co-workers (Dr. W. G. Steward and Dr. J. F. Kreider) from building a small scale model and integrating a 35-ft diameter reflecting dish into a house as shown in Fig. 2. Table III gives the cost breakdown for the 35-ft diameter SRTA unit. The cost of the absorber and the reflecting surface, which have not yet been completed, are extrapolated from manufacturers' cost projections and from the cost of the smaller unit which was completed in November 1974 and has been operating under winter conditions in Colorado. On this basis the cost of the 35-ft diameter SRTA unit is $5.75 per square foot of aperture surface, but considerable cost reduction can be expected with mass production.

Focusing solar collectors also offer potentials for economy of scale, i.e., reduction of cost per unit energy as the size of the system increases. Construction of a spherical dish with a radius of curvature of 870 feet "to an accuracy of 1.2 to 1.5 inches root mean square" is described in Ref. 10, the possible combination of a large SRTA collector system with a coal strip mining operation to produce cheap electric power is discussed in Ref. 11, and a comparative cost estimate extracted from a feasibility study by Environmental Consulting Services, Inc. to use solar energy for heating, cooling, and generating electric power for the Iowa State Capitol Complex is presented in Table IV. Cost estimates for a 10 to 100 megawatt Electric Power Production Facility consisting of a SRTA solar concentrator with no heat storage, backed up by a conventional fuel fired boiler, indicate that in a favorable location it should be feasible to produce electric solar power at a cost of about $700/KW. This is less than the projected cost for nuclear power.

The SRTA concept has been tested with a 2-ft diameter model in the Solar Laboratory of ECS. Fig. 3 is a schematic diagram of the experimental setup, the reflection pattern at various times of the day is shown in Fig. 4, and preliminary performance results are presented in Table 5. These results were obtained with a bare cylindrical absorber. Computer projections from Ref. 8 for the performance of the 35-ft SRTA unit with one glass cover over the absorber are shown in Fig. 5. It appears that with a 33:1 concentration ratio some diffuse radiation is collected and that an efficiency two or three times larger than for a flat plate collector can be achieved under environmental conditions prevailing during the winter in the Rocky Mountain States. Under these conditions the cost of energy delivered by focusing collectors is considerably less than useful energy delivered by flat plate solar collectors or the equivalent cost of an electric heating system.

The work reported here has been a joint effort by Dr. W. G. Steward, Dr. J. F. Kreider, and the author. The assistance of the Reynolds Aluminum Company, who provided the reflective coating for the SRTA test model, is gratefully acknowledged. The experimental test data presented at this workshop are preliminary and a more complete account of the performance and cost projections will be presented after the system has been fully evaluated.

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TABLE I
COMPARISON OF SOLAR ENERGY COLLECTORS

	Conventional Flat Plate Collector	Intermediate Concentration Collector	Tracking Reflector High Concentration Collector	Stationary Reflector High Concentration Collector
Solar collector surface movement	None	Infrequent	Continuous	None
Absorber movement	None	Infrequent	None	Continuous
Collection efficiency	Low	Intermediate	High	High
Heat losses	Large	Intermediate	Small	Small
Temperature of working fluid	Low	Intermediate	High	High
Carnot engine efficiency	Low	Intermediate	High	High
Potential for electric power generation	Poor	Good	Excellent	Excellent
Accepted radiation	Direct and diffuse	Direct some diffuse	Direct and little diffuse	Direct and little diffuse
Part of other construction potential	Good	Possible	Difficult	Good
Cost per square foot collecting surface	Intermediate	Intermediate	High	Low
Economy of scale	None	Some	Good	Excellent
Heat Storage Potential	Poor	Fair	Fair	Fair
Projected cost per BTU delivered	High	Intermediate	Intermediate	Low
Current Federal 1974 R&D funding	Substantial	Some	Large	None

TABLE II

Comparison of
Stationary Reflector-Tracking Absorber
with Flat Plate Solar Collector

Advantages	Disadvantages
1. Working fluid can attain high temperature.	1. Will not absorb much diffuse radiation (but it might be possible to combine with flat plate system).
2. Absorber is small and vacuum insulation and selective surface treatment become economically feasible.	2. The small absorber must track the sun (technically simple).
3. Same system for electric power and hot water.	3. Need one high pressure/temperature connecting line for working fluid from absorber.
4. Smaller storage volume because of higher temperature.	4. House must be appropriately designed architecturally.
5. No extra roof support and leakage protection necessary.	5. Reflectivity of concentrating surface may diminish with time and may require periodic treatment.
6. No danger due to glass breakage in hail or wind.	6. Untried construction method for reflecting surface, may need some R & D.
7. Potential low cost of retrofit installation to replace propane.	

TABLE III

COST BREAKDOWN OF 35-FOOT DIAMETER SRTA SOLAR ENERGY COLLECTOR SYSTEM IN 1974 DOLLARS

A. REFLECTOR

Frontal area 935 square feet, surface area 1247 square feet.

Component	Material Dollars	Labor Dollars
Supporting structure	249	356
Polyurethane foam	416	1485
Aluminum sheeting and adhesive	510	640
	1175	2454

B. ABSORBER

Surface material with coating	54	120
Glass enclosure with anti-reflective coating	974	40
Fittings	95	190
Tracking System	75	150
	321	516

The total cost of materials and labor $4500

Cost per square foot of frontal area $4.75

TABLE IV

COMPARATIVE COST SUMMARY FOR THREE SOLAR ENERGY COLLECTION SYSTEMS AND A CONVENTIONAL FUEL OIL SYSTEM TO HEAT, COOL, AND GENERATE ELECTRIC POWER FOR THE IOWA STATE CAPITOL COMPLEX (extracted from Environmental Consulting Services, Inc. Final Report prepared for Brooks, Borg, and Skiles, Des Moines, Iowa, August, 1974)

System	Capital Investment $	Annual Operating Cost - $/year
I. SRTA High Temperature with Rankine-Cycle	3,500,000	1,264,000
II. SRTA High Temperature with Absorption Cooling	3,200,000	1,298,000
III. Flat Plate Low Temperature with Rankine-Cycle	4,600,000	1,405,000
IV. Fuel Oil (Central Steam and Electric Chiller Plant)	900,000	1,196,000*

*Cost estimate based on 1974 fuel prices. Escalation of fuel cost at 5% per year will make solar system I the least expensive by 1980!

TABLE V

PRELIMINARY PERFORMANCE RESULTS OF SRTA COLLECTOR SYSTEM
(Courtesy of W. G. Steward)

DATE/TIME	T AMB °F	INSOLATION TOTAL BTU/HR FT^2	INSOLATION DIRECT BTU/HR FT^2	T OUT* °F	MASS FLOWRT LB/SEC	OUTPUT Q/A_e** BTU/HR FT^2	EFFICIENCY, % BASED ON INSOL. TOTAL	EFFICIENCY, % BASED ON INSOL. DIRECT
Run #1 near sundown - normal incidence								
11/17/3:30	58	190	176	101	1.19	86.3	45.3	49.0
Run #2 near sundown - normal incidence								
11/23/3:15	38	254	222	185	0.491	95.1	37.4	42.8
Run #4 higher output temp. - normal incidence								
11/26/1:25	42	313	300	427	0.153	82.7	26.4	27.6
Run #5 moderate output temp. - normal incidenc - considerable cloud								
11/26/2:00	42	162	115	267	0.136	42.2	26.0	36.7
Run #7 very low temp. - near sundown - incidence angle = 43.2°								
11/26/3:15	38	225	173	88	1.08	58.9	35.9	46.7

Notes: 1. This absorber consists of a selective black coated sleeve pressed onto a coil of copper tubing which carries the coolant water. There are indications that a large temperature difference exists between the sleeve and the coil. If this were actually the case unnecessarily high heat losses would result. In the future this possible source of losses will be eliminated by using the coil directly as the heat transfer and absorbing surface.

2. In the high temperature run #4 the water pressure was unintentionally allowed to fall close to the saturation pressure at 427°F. Thus, it is possible that some steam may have been discharged from the absorber and the heat collection and efficiency calculations would have been low, since they are based on assumed liquid.

3. Calculations show that a glass envelope on the absorber should significantly improve the performance.

* Inlet water temprature was 50°F for all tests.

**Q/A_e = heat flux per unit effective area, A_e, where

A_e = frontal area X cos (incidence angle)

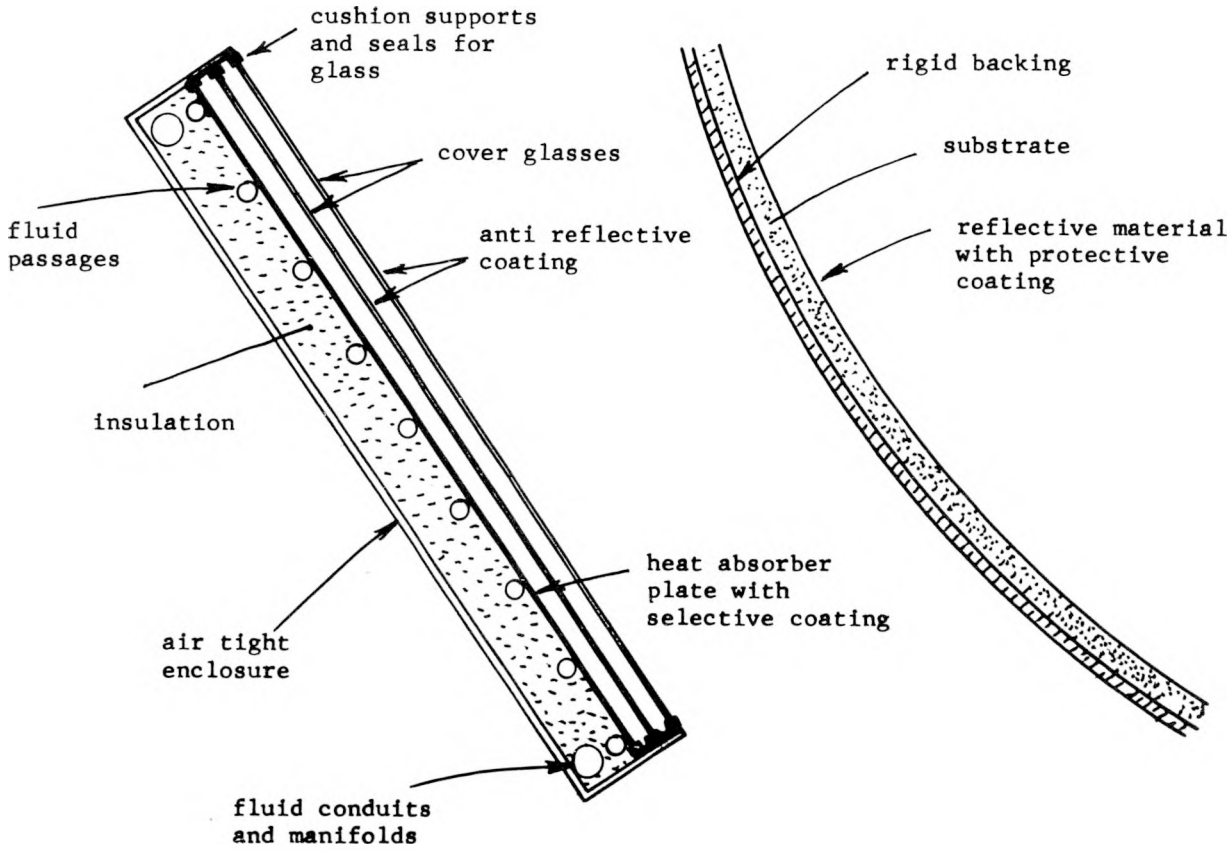


Fig. 1 – Cross Sections of a Typical Flat Plate Collector and Fixed Concentrating Reflector

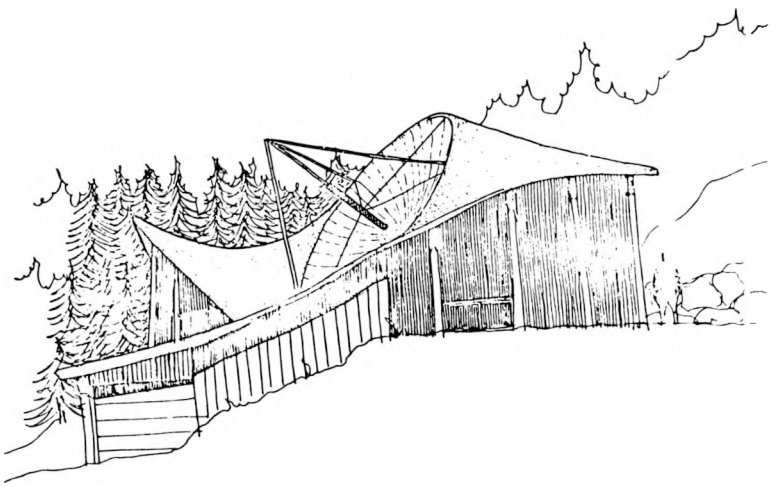


Fig. 2 – 35-Foot-Diameter SRTA Collector System Installed in Dr. W. G. Steward's Home, Sugarloaf, Colorado

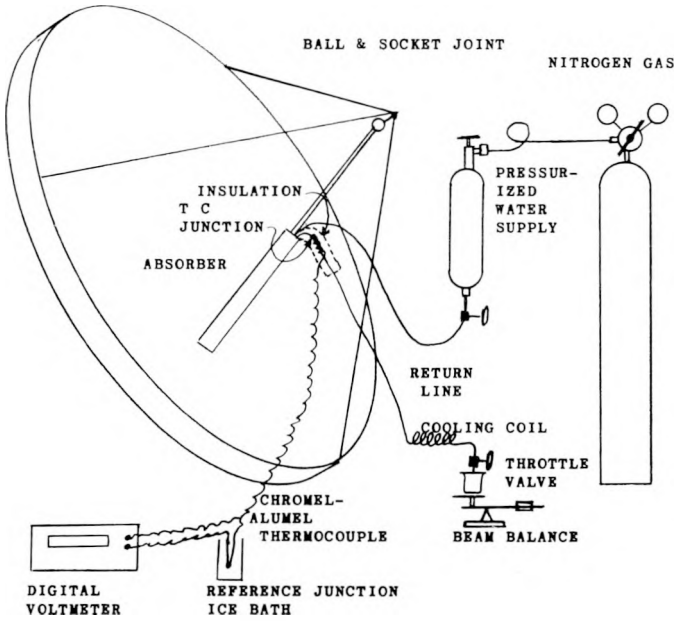
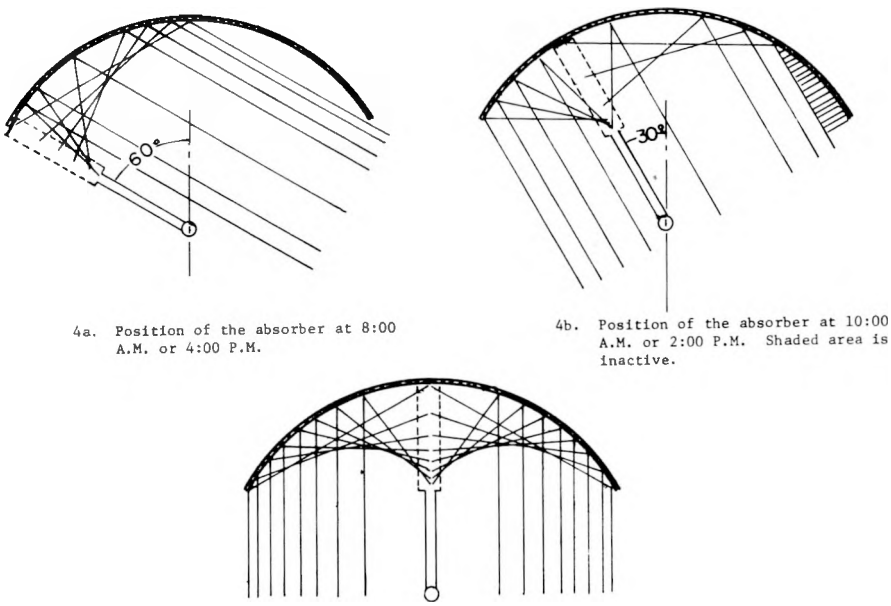


Fig. 3 – Schematic Diagram of Experimental Test Setup for a Performance Evaluation of SRTA



4a. Position of the absorber at 8:00 A.M. or 4:00 P.M.

4b. Position of the absorber at 10:00 A.M. or 2:00 P.M. Shaded area is inactive.

4c. Position of the absorber at 12:00 noon.

Fig. 4 – SRTA Reflection Patterns at Various Times of the Day

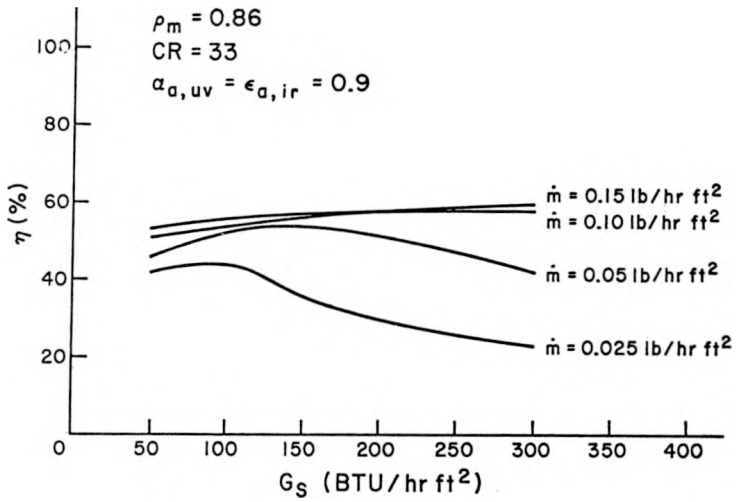


Fig. 5 – Analytical Projection of the Efficiency, η, of a SRTA Solar Collector System with a Glass Enclosed Cylindrical Absorber at Various Insolation Levels, G_S, and Mass Flowrates, $\dot{m}$

DISCUSSION

Question (William S. Duff, Colorado State University): What are the manufacturing cost estimates for the absorber heat exchanger and its supporting structure for the 15-ft-diameter collector? Also for the drive mechanism and absorber positioning controls?

Answer (Frank Kreith, Environmental Consulting Services): The economics of the absorber, using a nonselective surface, look like about 80 cents to $1 per square foot. The tracker is simply a clockwork equatorial mount that is used on telescopes, and we have discovered a very inexpensive photo diode system to correct for wind.

Question (Roy A. Lawrence, Ohio University): Please describe the reflector surface for the envisioned production reflectors.

Answer: It would be in 12-ft-diameter dishes, injection molded out of about 3-in.-thick polyurethane with reinforcing ribs cast in. No special adhesive is needed, as you can attach the reflecting surface directly to the foam in the injection process. It is a simple matter to hold the reflecting surface in position while the injection process is taking place. The surface is 20-30-mil alloy developed by Reynolds and tested over the last 3 years for another application.

Question (Frank DeWinter, Altas Corporation): Is the $700 per kW based on the collection period, or on a 24-hour average?

Answer: It is on a capacity basis, not averaged over the day. It is considered to be a peaking alternative to a gas turbine or similar equipment.

SESSION 4

PANEL DISCUSSION BY COLLECTOR MANUFACTURERS

(Written summaries were not received from Mr. Barber or Mr. Jenkins in time for inclusion in the Proceedings.)

52,092

THE DEVELOPMENT AND PRACTICAL APPLICATION OF SOLAR ENERGY IN AUSTRALIA.

FRANK.D. BAUER.
GENERAL MANAGER
BEASLEY INDUSTRIES PTY. LIMITED.
BOLTON AVE. DEVON PARK. SOUTH AUST.

1. INTRODUCTION

The solar water heating industry in Australia has progressed fairly rapidly because until recently there were no known supplies of natural gas, limited supply of hydro-electrical power and areas particularly in the northern parts of Australia, where power is very expensive.

This, coupled with a fairly temperate climate with an abundance of sunshine - "solar power" and with the encouragement of the Australian Government and assistance from the Commonwealth Scientific Industrial Research Organisation (C.S.I.R.O), the solar water heating industry in Australia was formed - refer photographs 1 to 4.

During 1972/73, 7000m^2 (75,300 sq.ft.) of flat plate collectors were manufactured in Australia. During 1973/74, corresponding figures were 8,800m^2 (94,700sq.ft.) which represents a 26% increase.

2. TYPES OF SOLAR HOT WATER SYSTEMS.

2.1 Thermo-syphon system: The most popular unit installed in Australia.

The standard domestic system generally consists of 4 only "Solapaks" measuring 4' x 2' interconnected either roof mounted or mounted as a window awning.

The 'Solapak' is usually 60 gallon capacity, low pressure and has a booster element 1.0 k.w. and adjustable thermostat mounted at the mid point of the cylinder. Where sufficient space is available, the 'Solatank' is mounted inside the roof area - refer photograph 5.

2.2 Forced circulation - because of the additional cost of a circulating pump, air eliminator, controlling thermostats, time clocks etc, this type of system has been mainly confined to industrial and commercial installations. There has been a sharp increase however in research on more efficient and cheaper forced circulation systems for domestic use. Small plastic pumps with a record of reliability are now coming on to the market. The C.S.I.R.O. are working on silicon cell type temperature controlling devices which are much more sensitive and hence increase the efficiency of the complete system, almost comparable to a "thermo-syphon" system.

2.3 *"Compact 100" - Compact type solar system has been developed to provide a cheap solar water heater, easy to install and to try and improve the aesthetics of the system. The system illustrated is a 100 litre (22 gallon) capacity and has an effective absorption area of 1.44m^2. It is fitted with its own cold water supply tank, controlled by a ball valve and float. This tank is adjustable so as to remain horixontal to suit the latitude of the area where the system is being installed.*

It is fitted with a 3.6k.w. booster element at the mid point of the cylinder which can provide up to 15 gallons of hot water raised 80^{O}F per hour in the event of no solar radiation. Tests just being completed in Adelaide, indicate that 30 imperial gallons of water at 56.6^{O}C (135^{O}F) can be drawn off with a temperature rise of 67^{O}F using only 1.73k.w. of electrical power which includes heat losses. This represents an efficiency of 70.1% - Refer photograph 6.

2.4 *Solar "Pre-heater" - As the name implies, is a system to pre-heat the cold water before it is fed into the cold water inlet of the existing system, either powered by electricity, gas or oil. The Pre-heater has a small inbuilt storage cylinder - 6¼ gallon capacity, has no booster element and is capable of withstanding mains pressure up to 100 p.s.i. Depending on hot water usage patterns the "Pre-heater" can provide up to 35% of the daily hot water requirements. - Refer photograph. 7 .*

2.5 *Heat Exchange type - Any of the previously mentioned solar hot water systems can be designed with an inbuilt coil heat exchange system which is connected directly to the 'Solapak'. Advantages of this system are that the 'Solapak' can have Ethylene Glycol added to decrease the feezing temperature, conditions as such which are experienced in large areas of the United States. The disadvantages of this system is the increased cost and the drop in efficiency due to the decrease of thermal conductivity of water when Ethylene Glycol is added.*

3. *GENERAL CONSTRUCTION OF SOLAR HOT WATER SYSTEMS.*

The Beasley 'Solapak' absorber panel is constructed of copper to which have been thermally bonded copper tube waterways. The absorber panel is chemially treated to provide a "selective surface" which has an absorptance of 0.85 to 0.90 and an emittance of 0.10 to 0.15.

The whole assembly is enclosed in a galvanised, insulated weather proof box, covered with either a single or double sheet of 32 oz. (4mm) clear glass - Refer photographs 8 and 9.

Beasley 'Solatank' is also constructed of copper and insulated with 3" mineral rockwool.

Life expectancy of the complete system is expected to be in excess of 15 years.

4. *COST OF FLAT PLATE COLLECTORS*

Copper has become accepted in Australia as the most satisfactory long life material for the construction of flat plate collectors. This has been because of two major factors.

4.1 *Known long life of copper in the areas of Australia where water conditions would preclude the use of materials other than copper.*

4.2 *Coppers excellent heat conductivity properties, together with its abilities to accept "Selective Surface".*

Because of coppers unstable price structure, alternative materials with properties similar to copper are being investigated. To date aluminium appears the most likely substitute, being reasonably stable in price, good conductivity and with some additional research, capable of accepting a suitable "selective surface" similar to copper.

Based on a standard 4' x 2' (0.75m^2) assembled 'Solapak' the material cost could be reduced from $21.90 for a copper absorber to $16.80 for the aluminium absorber. These costs still provide for the use of copper waterways and heater tubes in the construction of the 'Solapak'.

5. *INDUSTRIAL APPLICATIONS.*

The largest solar hot water installation in South Australia, is at the Sacred Heart Boys College, Adelaide, where two 450 gallon Beasley 'solatanks', in conjunction with 80 (640sq.ft.) Beasley 'Solapaks' operate in two banks on the forced circulation principle, with boosting by an oil fired boiler. Refer photographs 10 and 11.

The system supplies 800 gallons of hot water daily and has been in operation for 8 years. Savings in operating cost is 70%.

Qantas Empire Airways in Darwin have nine groups of flats each with a 400 gallon Beasley 'Solatank' and 32 'Solapaks'.

In this case, solar energy provides a total of 3,000 gallons of hot water daily with a saving in operating cost of more than 90%.

6. *THE FUTURE.*

There are approximately 4 million dwellings in Australia and it is estimated that by the year 2000 there will be 7 million.

With the advent ofcheaper solar absorbers and increased fuel costs, a growth rate in the production of absorber panels in excess of 35% per annum can be expected. This could result in production in Australia increasing to 8 million M^2 (86 million sq.ft.) of absorber panels per annum by the year 2000.

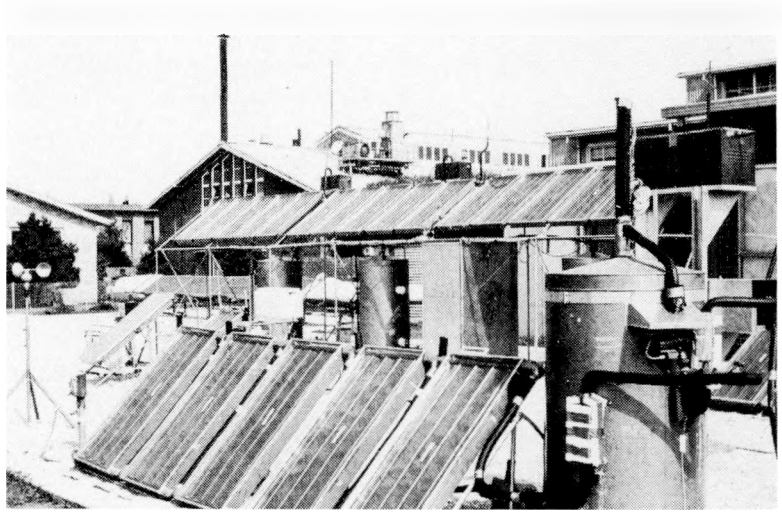


Fig. 1 — Testing of Solar Hot Water Systems at C.S.I.R.O., Melbourne, Australia

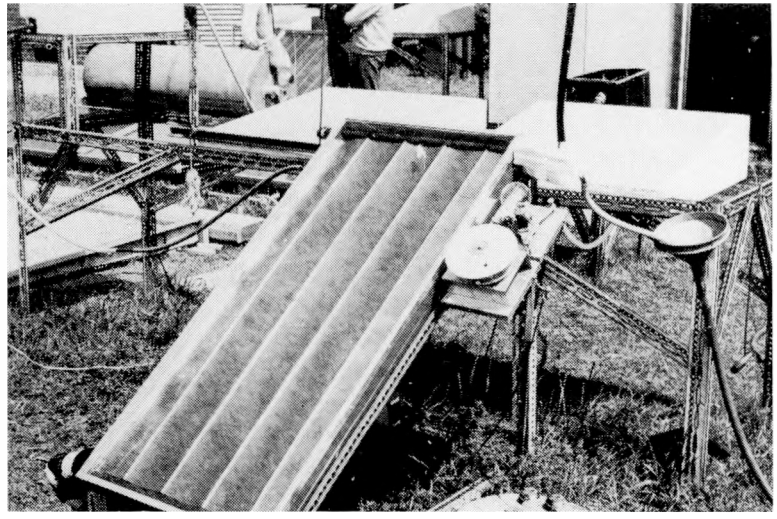


Fig. 2 — Efficiency Test on a Standard 0.75 m^2 Beasley Solapak at C.S.I.R.O.

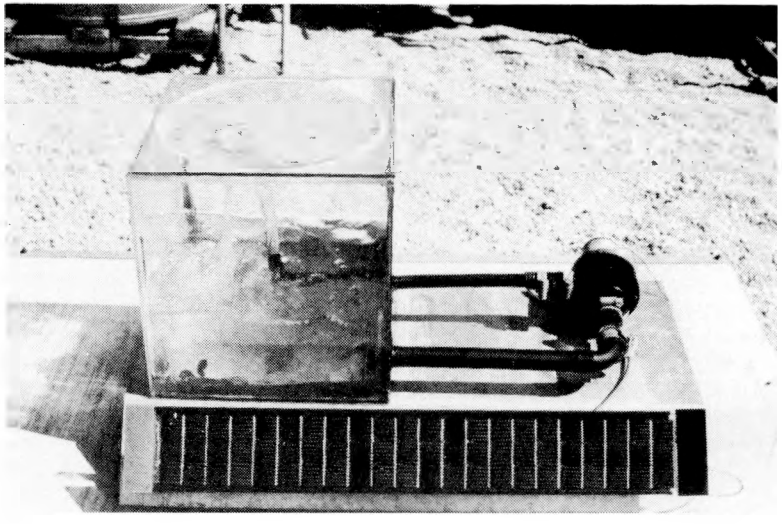


Fig. 3 — Experimental Solar Pump at C.S.I.R.O.

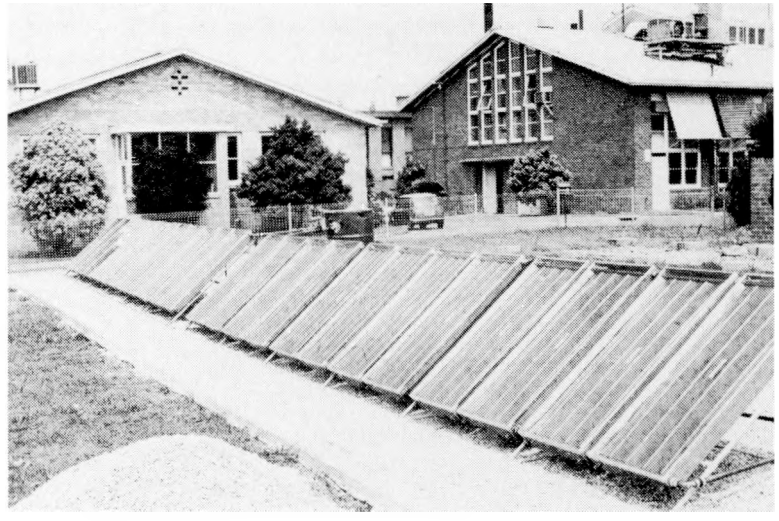


Fig. 4 — Test on Methods for Interconnecting Solar Panels for Forced Circulation System at C.S.I.R.O.

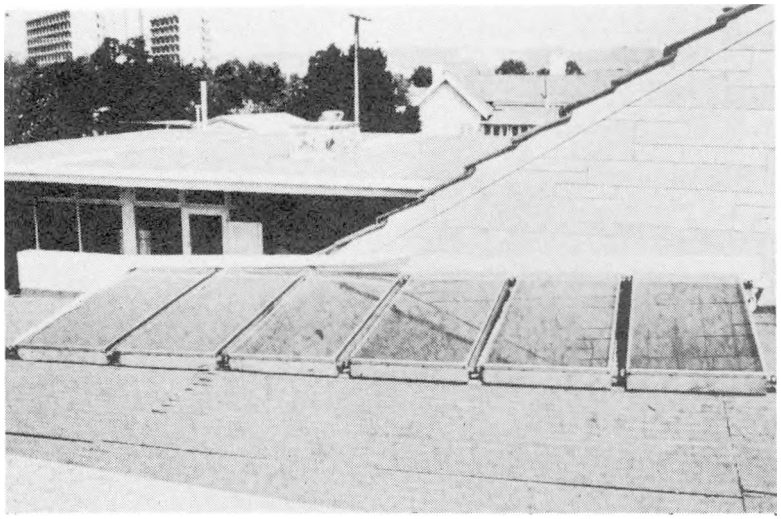


Fig. 5 — Typical Thermo-syphon System, Adelaide, South Australia. Solatank Inside Roof Space

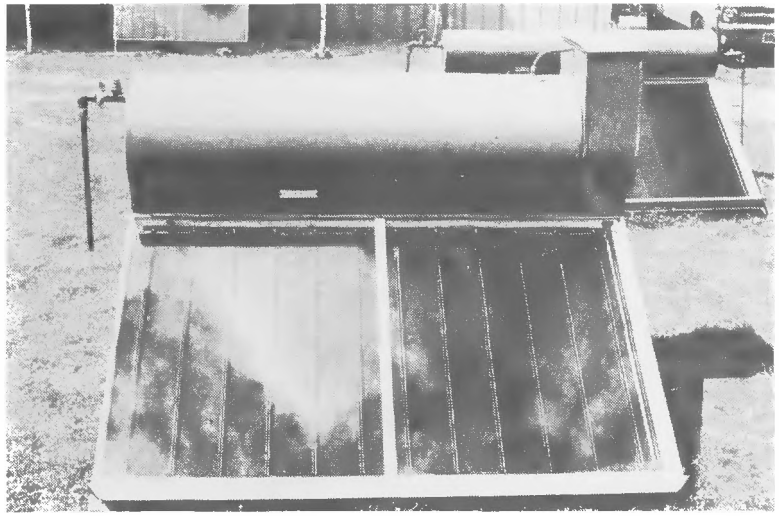


Fig. 6 — "Compact 100" — Self-Contained Solar/Electric Hot Water System

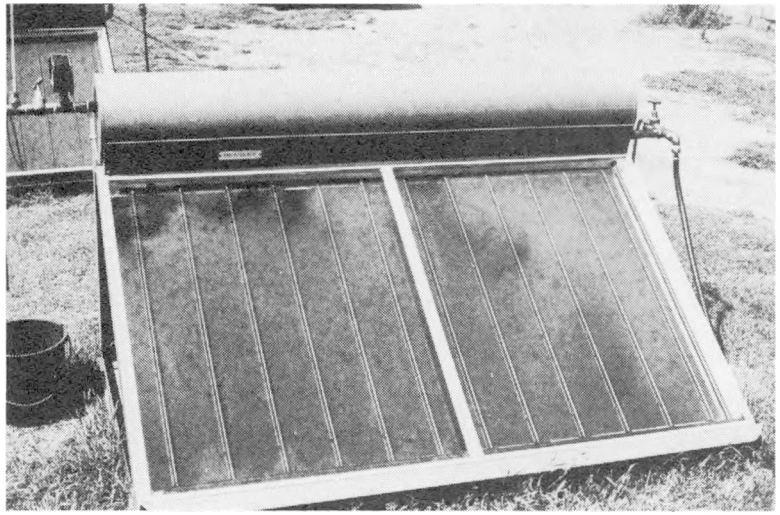


Fig. 7 — Solar "Pre-heater" Used in Conjunction with an Existing Water Heater

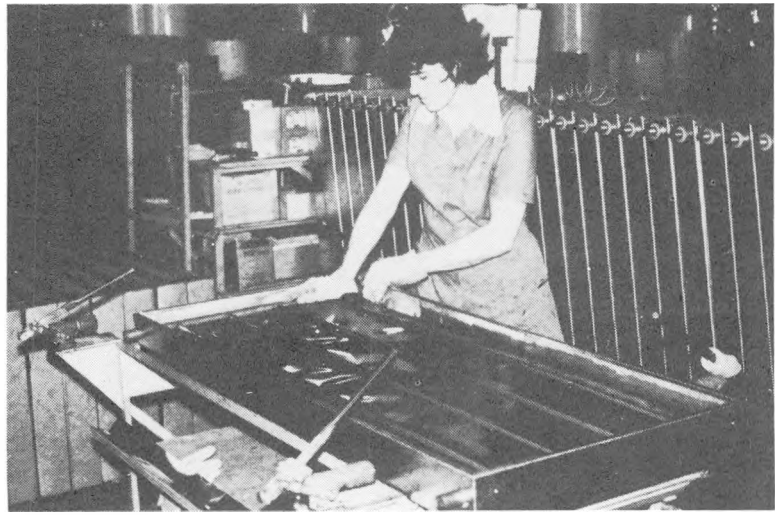


Fig. 8 — Assembly of Copper Absorber Panel into Galvanised box — 'Solapak'

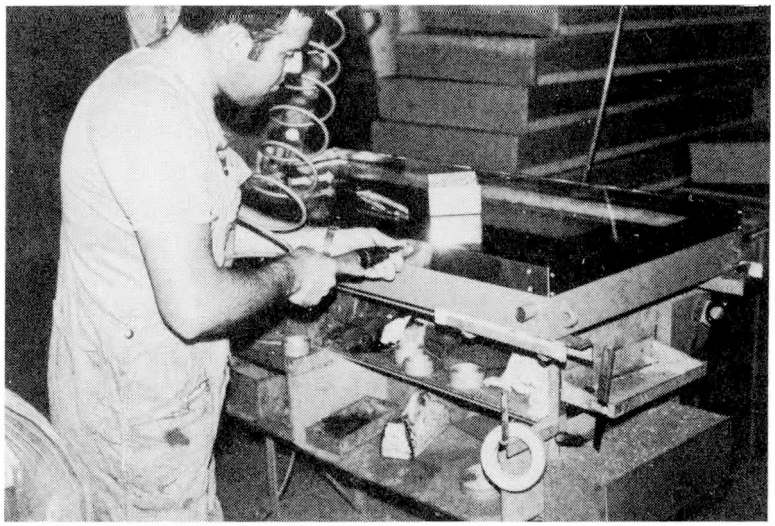


Fig. 9 — Assembly of Aluminum Trim to a 'Solapak'

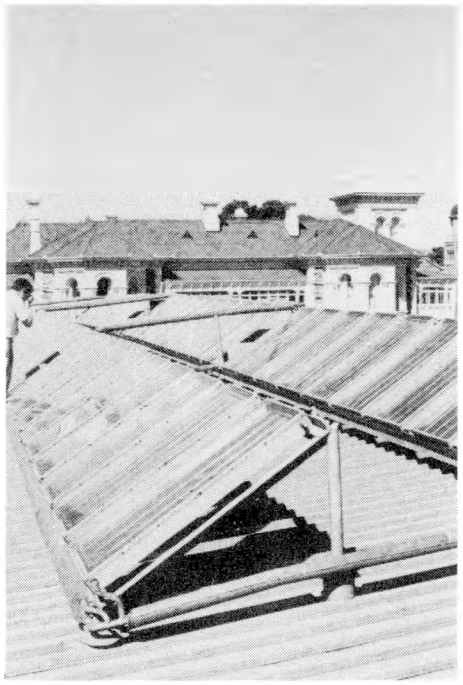


Fig. 10 — Solar Installation— Sacred Heart College— Adelaide, South Australia

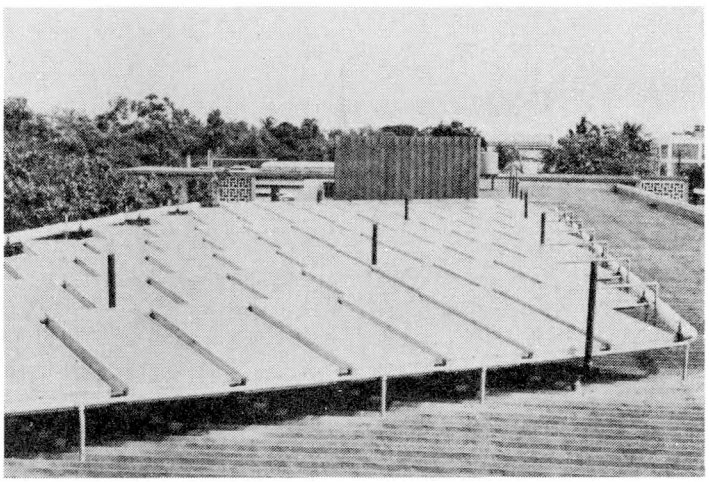


Fig. 11 — Solar Installation — Don Hotel, Darwin, Australia

DISCUSSION

Question (Frederick N. Broberg, Hill & Harrigan): What is the cost of your collector panels per ft^2—material plus installation, f.o.b. New York?

Answer (Frank D. Bauer, Beasley Industries): The cost of Solapak (0.75M) is $7 per ft ex factory at Adelaide; that is the retail price. Installation cost is dependent on local material and labor costs and environmental conditions such as insulation requirements.

Question (Mr. Broberg): Do you have performance curves available for your collectors?

Answer: Yes, available on application to consulting engineers.

Question (Charles P. Turner, National Oceanic and Atmospheric Administration): What prevents thermal runaway of water heaters, i.e., water in the collector panel and/or whole system exceeding the boiling point and possibly rupturing system parts?

Answer: The thermal runaway is normally controlled by selection of absorber area and storage cylinder capacity. The rupturing of the system through overheating is prevented by inclusion of a pressure-relief valve, which is a normal requirement in mains or controlled-pressure water heaters.

Question (Mark Hyman, Jr., Solar Heat Corp.): What is your selective surface?

Answer: The selective surface as applied to the Beasley collector is a thin film some 5-12 microns in thickness of black semiconductor (cupric oxide) on a copper substrate absorber.

Question (George B. Cain, Copper Development Association, Inc.): What is the relative flow rate in the different vertical tube sections?

Answer: There is no flow differential; the same flow rate must be achieved in all vertical tubes for maximum efficiency.

Question (Mr. Cain): What is the inside diameter of the copper tube, its wall thickness, and the panel thickness?

Answer: The outside diameter is one-half inch; thickness is controlled by design pressure. Panel thickness is controlled by the spacing of the risers to give maximum efficiency for minimum cost.

Question (Mr. Cain): What is the cost of panels versus complete systems?

Answer: The cost of a Solapak absorber ex factory is $56 retail ($0.75M^2$). Installation will be dependent on local material and labor costs and environmental conditions, etc.

Question (Mr. Cain): Have there been any failures from internal corrosion?

Answer: Absorbers have been removed from a 7-year-old installation in Adelaide with water up to 200-ppm hardness, cut open and inspected, and have shown no appreciable degradation.

Question (Steven M. Ridenour, Dubin-Mindell-Bloome): Do you try to prevent condensation on the under side of glazings; or on the absorber? Or, do you try to live with it, such as providing for condensation weepage?

Answer: (Frank D. Bauer, Beasley Industries): We provide weepholes, and it was one of the problems at Sacred Heart College that those weepholes did cause a problem through water lodging in the angle iron support frame

and weeping into the insulation. We disagree with Mr. Thomason on this score, that condensation does affect the efficiency of the unit. It tends to form corrosion inside your box. We try and do high-pressure water spray tests on batch quantities to make sure that the sealing strip underneath the glass, and all the fittings outside the box, are completely sealed. We go to a lot of trouble to try and stop condensation. I don't say that we have stopped it in every case, but we have stopped it in most cases we think are serious.

Comment (Stephen J. Winter, Guam Energy Office): A Japanese company (Sekisui) manufactures a solar water heater in which the collector—consisting of about six 8-inch-diameter plastic tubes—also serves as a storage "tank." Would you comment on the pros and cons of this system, perhaps comparing it with a Beasley unit.

Response: The Japanese-style collectors, combining both solar absorber and storage cylinder (manufactured from 6-inch-diameter plastic tubing), exhibit poor stratification and serious heat loss characteristics. In stratification, there is a serious drop in water temperature for small water drawoffs. Temperature drops approximately 5° F for every 3 gal of water drawn. As to heat loss, overnight cool-down occurs. With a 70° F average ambient temperature overnight, the temperature of the water contained within the cylinder dropped from 130° F at midnight to 90° F at 7 a.m.

52,093

EXPERIENCE IN THE MANUFACTURE AND SERVICE OF SOLAR WATER HEATER IN MIAMI, FLORIDA

By William R. Robbins, Jr.
Owner of W.R.Robbins & Son Roofing Co.
Miami, Florida

For the past 30 years our company has been engaged in the solar water heater business in Miami which includes installation of new systems and service work on old systems. This experience with the older systems is what I will spend most of my time with tonight. This field experience will be of interest to you mainly because you can see from photographs what happens to the components of a solar water heater system after 5, 10 or even 40 or 45 years.

We will show which materials or combinations of material will not only heat water but will stand the test of time in the South Florida climate. Furthermore which methods of securing the collector to the roof structure are best in terms of long service for the collector pan and long life for the roof membrane under the hot collector.

These questions should be asked of today's new collector designs and installation plans. Long life free of service costs is a necessity if the amortization of initial costs is to be realized over a reasonably long period of years.

Figure 1 shows a typical South Florida solar water heater. If has an all copper coil of 3/4" water tube soldered to a thin copper sheet for backing. This particular collector is 12 feet long and 4 feet wide. It has an 80 gallon galvanized steel tank and provides sufficient hot water for a family of 3 or 4 people at today's rate of consumption. When it was originally designed 40 years age it would serve the needs of 6 people. This particular system has been operating on our building since 1947 without any service or maintenance. The tank is original.

Some of the earlier designs used some pressure treated wood in the box but this would not last and now the best pans are made of galvanized steel.

Figure 2 is a close up of the same collector; the glass is single strength solidly glazed in the pan.

The same collectors can be connected in parallel to heat much larger tanks for multi-unit buildings.

Figure 3 is a pair of 315 gallon tanks on a 10 unit apartment building; each tank has two 58 square foot collectors connected. This system has been operating since 1948 with very little maintenance.

In some the earlier systems galvanized iron water pipe was used in the collector instead of copper. This was a mistake as it would crystallize and lime up at the joints and fittings causing leakage and reduced circulation.

Figure 4 shows a sample of this problem. All collectors being made in Miami now use copper.

Another critical area in the solar system is the joining of copper circulating lines to the galvanized steel tank. Figure 5 shows the greatly reduced opening due to calcification which happens after 6 or 7 years if the wrong size brass fittings are used on the tank. Galvanic action

ultimately causes tank failure but this closing down of the opening will occur long before the tank will leak.

In the past attempts to prevent galvanic action have been made by using plastic bushings to separate the steel and copper but this was innefective because the water carries the problem. The important thing here is to use the largest size fitting possible where dissimilar metals meet.

The solar tanks are extra heavy duty 300# test galvanized steel and they usually last at least 15 years.

Figure 6 shows a typical house with the solar collector mounted in a tile roof and the tank above it in a housing designed to look like a chimney. When this house was built in the late 1940's practically every new house has a solar water heater.

Figure 7 is a close up of a collector mounted in a tile roof. Here it is important that the collector be mounted on brackets to provide an air space above the roof membrane or the membrane will age prematurely due to heat from the collector.

This lack of air space will also cause the galvanized iron pan to rust out necessitating replacement by putting the old copper coil in a new pan.

At the present time we are testing a number of different collector designs to be used with the familiar thermosyphon systems and with forced circulation systems to be added to electric water heaters or swimming pools.

Figures 8, 9 and 10 show some new designs under study.

In summary I hope our experience with solar equipment and materials will be of benefit to you in terms of planning for long life of the collector, storage tank and the roof structure it is fastened to.

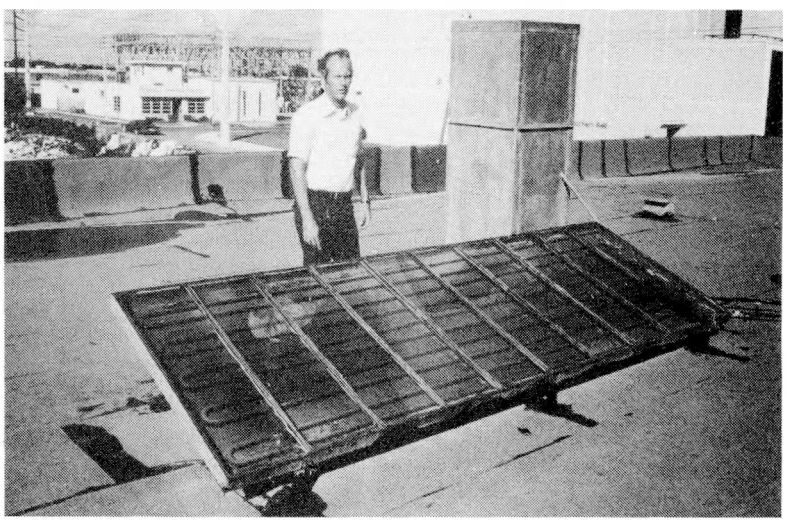


Fig. 1 – Typical South Florida Solar Water Heater



Fig. 2 — Close-up of South Florida Collector



Fig. 3 — Solar Water Heater for 10-Unit Apartment Building

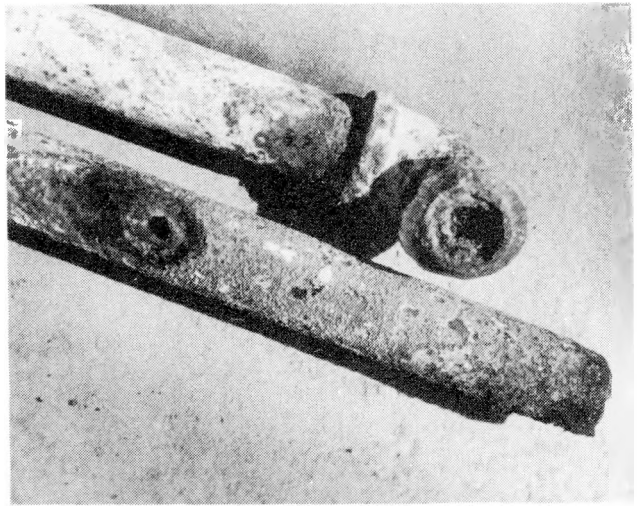


Fig. 4 — Galvanized Iron Pipes Showing Damage from Galvanic Action

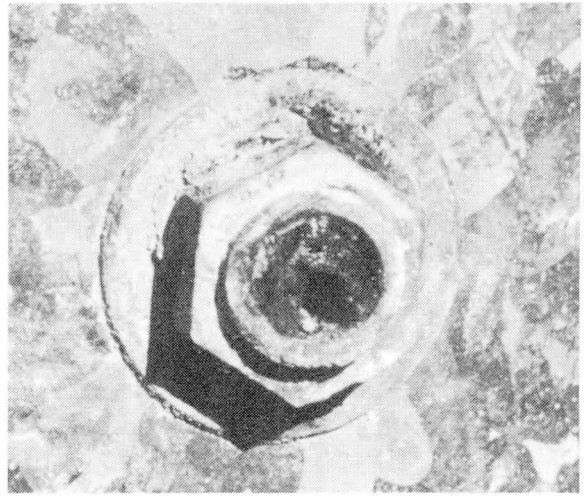


Fig. 5 — Solar Water Heater Tank with Restricted Opening Due to Galvanic Action



Fig. 6.– Miami House with Solar Water Heater



Fig. 7 – Collector Mounted in Tile Roof

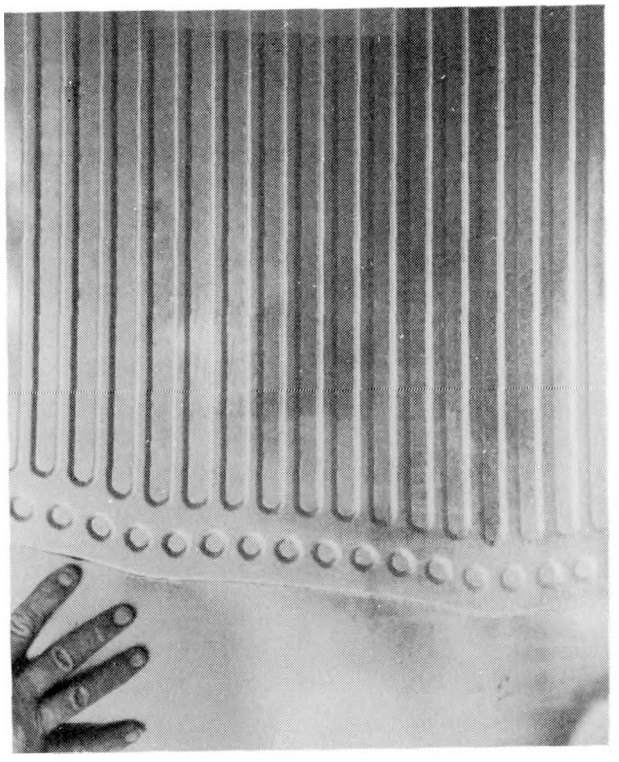


Fig. 8 – New Copper Collector Plate Design



Fig. 9 – Collector Plate Design Currently Under Study

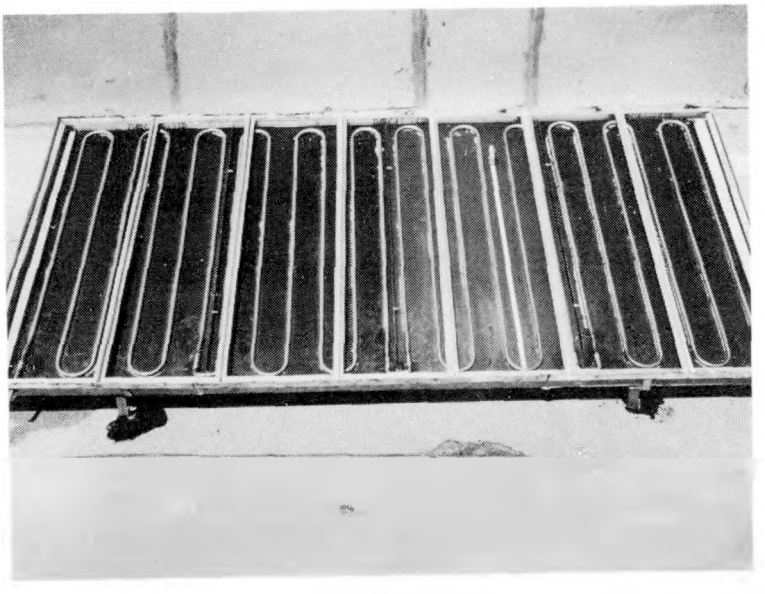


Fig. 10 – New Collector Design Under Study

DISCUSSION

Question (Stephen J. Winter, Guam Energy Office): Do your collectors and tanks operate at normal house-line pressure, or are they low-pressure systems (regulated by a float valve)? If the former, what is the line pressure?

Answer (William R. Robbins, Jr., W. R. Robbins & Sons Roofing): The collectors and tanks operate at normal house-line pressure, which is usually 60 psi.

Question (Steven M. Ridenour, Dubin-Mindell-Bloome): Do you try to prevent condensation on the under side of glazings, or on the absorber? Or, do you try to live with it, such as providing for condensation weepage?

Answer: We don't try to make the collectors airtight. We put weepholes in the bottom and, in addition, we are now coating the inside of the pan with asphalt—either hot asphalt or plastic cement—to retard the corrosion.

SUMMARY OF REMARKS BY

R.R. LEWCHUK
PPG Industries, Inc.
Pittsburgh, Pennsylvania

In the decision to produce solar collectors, PPG Industries reviewed the literature concerning solar energy. It was found approximately 20 years ago that utilization of solar energy as a means to heat buildings and provide hot water could not yet become a viable business opportunity due to the relative cost of existing fossil fuels.

Solar energy development for the Company then laid dormant until this past year (1973). We reviewed the energy situation, the market, and our ability to produce a product with existing facilities.

As a result, PPG Industries decided to become not a total system supplier but a component supplier of certain parts and the total flat plate solar collector. We will supply tempered glass for those interested in producing their own solar collector or system. We will also provide double glazed units that can be fitted over other solar collector absorber plates or systems. And, of course, we will supply the total flat plate solar collector component.

Fifty miles north of Pittsburgh in Ford City, Pa., we have a manufacturing facility that has the capacity of annually producing 3-5 million square feet of solar collectors. We have been in production of solar collectors since June of 1974. They are commercially available.

Briefly describing the PPG Baseline solar collector, it is a 34" x 76" self-contained unit comprised of the following: double glazed with 2 pieces of 1/8" tempered glass; the outer ply needs to be tempered to withstand windload, hail and vandalism. The inner ply needs to be tempered to withstand the thermal stresses that can be induced in glass from temperature differentials. We offer an aluminum Rollbond® panel as the absorber plate. We also produce a collector with a copper panel as the absorber plate. The absorber plate is backed with fiber glass insulation and can be enclosed with a metal housing for weatherproofing. Connections are provided normal to the back surface. The unit is sealed to prevent moisture from accumulating in the air space surface. The absorber coating is our PPG Duracron® enamel which has been used in the spandrel areas of buildings for many years. It has an absorptance/emissivity ratio of 1.0 (95% absorptance). Although the above does not tax the limits of the technology, we have put together materials we believe are durable, will perform, and offered them at a published price. We have applied what we have learned over the past 40 years in the business of insulating glass to produce a highly cost-effective, trouble-free baseline collector.

As far as the subject of guarantee is concerned, because of the temperatures encountered in solar collectors, we do not yet know how long this product will ultimately perform. We have exposed the product to standard accelerated tests. Many of these tests can be found in the standards

governing insulated glass units. However, because of the lack of field history at the elevated temperatures, we do not yet know how long the collector will perform.

The current prices for the PPG Baseline collector and options have been published. The first option is a complete double glazed collector with insulation exposed on the back at $6.00/square foot. The insulation is left exposed for those who can provide their own superstructure. The second option is where we provide a metal housing covering the insulation on the back of the collector for weatherproofing. This is offered at $7.20/square foot. Please realize that costs are increasing - current prices can be gotten by contacting PPG Industries.

With the Baseline collector, we now have something against which to compare new developments in solar collector technology. New developments must be evaluated to determine whether any improvement will be cost effective.

PPG Industries is thoroughly committed to developing and improving products for solar collectors. We have research programs in progress toward developing improvements.

PPG Industries believes that because of the undefined market in the area of solar energy, that only those with existing facilities should get into the solar collector business. The undefined market places a solar business in a high risk capital venture at this time. For those that have existing facilities which produce similar products, the capital investment is not required and solar energy products can then be classed as product extensions or application of similar products toward new technology.

We believe that an aluminum absorber plate can be effectively utilized in solar collectors as long as one engineers correctly with the material. We do not advocate using untreated water through aluminum absorber plates because of potential corrosion problems. (Mr. Sheldon Butt of Olin Brass Corp. will address this subject in his talk.) We do believe that because of the freezing problem in all areas in the country north of a line through central Florida, that special antifreeze fluids will be required in contact with the absorber plate in liquid systems. This, then, with other good engineering practices, should minimize the potential problem.

In conclusion, PPG Industries has a commercially available solar collector. We have drawn on our 40 years of experience of insulating glass technology to put together what we believe is a durable, cost-effective solar collector. As we develop improvements, we will be able to contrast these with this Baseline collector to evaluate whether these improvements are truly cost-effective. We currently have the capability to annual produce 3-5 million square feet of solar collectors. Because of the undefined market with solar energy products, we advise against those getting into the business unless they are currently producing similar products.

DISCUSSION

Question (Roger Gillette, Boeing Aerospace): How long do you expect the desiccant to remain active in your collector?

Answer (Richard R. Lewchuck, PPG Industries, Inc.): Although we do not have the "test of time" under field conditions with our collectors, we do expect the desiccant to last the life of the unit.

Question (Harold R. Hay, Skytherm Processes): How much room do you see to reduce your collector cost in the next 5 years?

Answer: With inflation and the price of materials continuing to rise, we do not expect to be able to reduce the price of the collectors. However, we do expect to make advances or improvements in efficiency so that one can do the same job with fewer square feet; this then should translate into less cost.

Question (Unidentified): You stated your production facility can produce a million square feet of collectors per year. That sounds like a lot. Can you tell me what percent of the new construction per year can be equipped with collectors at that rate?

Answer: Our facility at Ford City, Pa., has the potential capability to produce 3-5 million ft^2 per year. To produce for just 1 percent of the potential residential market would require the construction of new and larger production facilities.

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SUMMARY OF REMARKS BY

HARRY E. THOMASON
President
Thomason Solar Homes, Inc.
Washington, D.C.

Solar heat collectors should not be studied in a vacuum. They must be studied with regard to their cost first. If they are too expensive they cannot pay for themselves. Therefore, efficiency is worth little more than academic discussion.

If the cost is low enough (say $3 to $5 per square foot), then the life expectancy should be examined. If the life can be raised to 15 to 20 years or so, we should then look to the system to be used.

If the system must use heat stored at 100° F and above to keep the home warmed to 65° F, then it makes little difference what the efficiency of the collector would be when operating at 65 to 100° F. On the other hand, a Thomason "SOLARIS" System uses heat collected and and stored at 65 to 100°F. Therefore, the (patented) "SOLARIS" heat collector operates at high efficiency in its normal operating range of 65 to 100° F. Therefore, operating at "normal" in a "SOLARIS" System means collecting and storing heat at 50 to 70% efficiency with the simple, low-cost "SOLARIS" collector.

Others pay from $7 to $17 per square foot for collectors. New Thomason "SOLARIS" collectors are on the market at $3 per sq. ft. Early crude tests indicate efficiencies of 50 to 70%, heating water on cold winter days for a "SOLARIS" home. The panels are approximately 4 feet wide by 16 feet high. They are very lightweight, only 3/4 pound per sq. ft. without glazing, only 2-1/4 lb./sq. ft. with single strength glass cover.

One glass cover is better than two in actual "SOLARIS" installations. A second cover would reflect away more energy than it would conserve. Others have shown that two covers are an asset to efficiency only when collection temperatures are about 85° above ambient air temperatures. In "SOLARIS" Systems, collection is about 50° above ambient temperatures. (Cold sunny day, ambient about 45°; heat collection at about 95° F.)

One glass cover is better than two also because it is much less expensive, lighter in weight, less expensive if replacement becomes necessary, no problem with dust clouding the inner pane, no inner pane to crack up as in other collectors, etc.

The "SOLARIS" collector has a low thermal capacity; therefore it warms up quicker and does not waste as much heat at sundown or when a cloud passes over the sun. (A thin lightweight aluminum collector sheet, with lightweight Fiberglass insulation, keeps the thermal capacity low.)

"SOLARIS" heat storage, in a tank of water filled with free rain from the sky, surrounded by stones from the field, makes low-temperature heat useful. That (patented) storage equipment heats the home with heat collected at 65 to 100° from the "SOLARIS" collector. Therefore, as mentioned

above, the system must be examined in its entirety. Ability of the low-cost "SOLARIS" collector to operate at high efficiency is dependent on use of the heat collected at low temperatures. Similarly, ability of the "SOLARIS" storage equipment to store enough heat for cloudy days and nights depends on its ability to deliver up heat from storage to the home air at low temperatures.

For air conditioning, here again the storage equipment is important. The patented "SOLARIS" air conditioning equipment uses the heat storage equipment reversely. Cold dry air is produced at night, by a small compressor and air conditioning cooling coil. That air is blown through to cool and dry the stones. Next day, warm muggy air from the home is blown through the stones to cool and dry it. Less energy is used, and afternoon brownout and blackout problems are not accentuated (the compressor operates at night.)

In the "SOLARIS" System, substantially all valves and all dampers can be eliminated. Automatic controls can be extremely simple and low in cost (only one thermostat, one time switch, and one solar heat collector pump control--for both solar heating and air conditioning).

In summary, the solar collectors should not be considered without noting their effect on an entire system. All considered together, each should complement the other.

New "SOLARIS" collectors omit earlier-used materials that deteriorated (such as Mylar, redwood and old-type ordinary calk) inside of the heat-producing high-vapor area. Instead, G.E. Silicone, glass, vinyl and aluminum are used, with high-quality paint to protect the corrugated heat collector sheet. We have used some of those materials for about 10 years in similar environments. We believe a 20 year life, or greater, can be achieved.

Indeed, we will guarantee the "SOLARIS" Systems in the new houses we are building. We will guarantee that no more than one tankful of oil (550 gal.) will be used during 12 months, for both domestic water and home heating. And, the apparatus will be guaranteed for five years, with $1,000 of the profits being set aside, with interest, to back up the guarantees.

Homes heated and cooled by electricity cost America about $17,000 for generators and other heat-producing and cooling equipment (about $14,000 for generating and $3,000 for heating-cooling equipment. Homes heated by conventional (oil) and cooled by electric equipment require $3,500 for apparatus in the home, plus about $3,500 for generators on hot afternoons to keep the home cool ($7,000 total).

"SOLARIS" heating-cooling equipment costs about $4,500. Using off-peak electricity, produced at night, no extra generators are needed. So, the initial installation cost of a "SOLARIS" System is far cheaper. And, operating costs are lower, both winter and summer.

DISCUSSION

Question (F. W. Hoffman, Phillips Barratti Engineers): What are the moisture problems, if any, with open water in collectors?

Answer: In normal operation, a "SOLARIS" glass cover, substantially sealed to the collector sheet as now in production, soon has a great deal of pure distilled water on its underside. That is similar to a solar still. The condensed but warm droplets soon drop back into the flowing streams below, thereby conserving that heat and water. Virtually no cold air enters. Virtually no warm vapor escapes.

A Yellott SOL-A-METER was used to scan the cover glass. Despite a whitish appearance, only 15 to 17 percent is reflected from the glass, plus the water droplets, plus reflection from the (imperfectly) "black" collector sheet, plus reflection from the water running in the valleys. Reflection from ordinary glass, plus the imperfectly "black" surface, when dry, is almost as high. Therefore, there is no appreciable reflection due to the pure, distilled water droplets.

Indeed, if a person stands looking at the collector glass from the same angle as the entering sun rays, the condensation can hardly be seen. That is, with the sun on the back of your head, looking into the collector as sun rays do, the distilled clear water droplets are substantially invisible.

The full story as to the optics and physical principles involved are being worked on in an attempt to find why the efficiency is so unexpectedly high in the new "SOLARIS" collectors.

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52,096

A BRIEF REVIEW OF FAFCO, INC., EXPERIENCE IN THE DEVELOPMENT AND MARKETING OF A LOW-GRADE HEAT SOLAR HEATING SYSTEM

Freeman A. Ford, President
FAFCO INC.
138 Jefferson Drive, Menlo Park, CA. 94025

Introduction

Perhaps the overriding lesson of the last five years of development and marketing of our solar heating system is that economics are paramount to every stage of development. The economics are bounded on one side by manufacturing costs and on the other by what the customer can afford to pay for the complete heating system, recognizing the very diffuse nature of solar energy and the large collector areas required. Equally important has been the overall systems approach, as very little is accomplished by offering the marketplace a collector without the associated hold-down and inter-connecting hardware, controls, etc. From a manufacturing standpoint, the following are essential: (a) a very high through-put; and (b) a capital intensive/low-labor input process with single conversion from raw material to finished product. Finally, the choice of the right entry point into the market is extremely important, as it would make little sense to start off with thermal power generation, when a need for low-grade heating equipment had gone unfulfilled.

FAFCO, INC., has chosen the heating of swimming pools as an entry point because it is a low temperature application, provides its own circulation and storage, and is located in a relatively concentrated manner where sunshine is generally most available.

History

Our work was started in late 1970 with about six months of intensive study of the existing hardware and processes in the solar energy field. This lead rapidly to interest in the swimming pools as an entry point; and, subsequently, to a good deal of theoretical work on the heating of swimming pools with solar energy. In 1971 a combination metal/plastic collector was prototyped and installed to verify the theoretical work of the previous winter. In 1971 a monolithic ABS plastic panel was developed and a number of these systems were sold to begin developing field experience with shipping, installing,servicing, and the performance of solar swimming pool heaters. In 1973 a monolithic polyethelene panel was developed and late in the year prototype high-rate production machinery was also prototyped. In 1974 we switched to a much higher-grade material made of polypropylene and the production machinery substantially upgraded to increase

both processing speed and control over the many variables involved in the process. Throughout the development of this machinery, advantage was taken of the extremely high technology resources available on the San Francisco Peninsula, but this was always tempered with the necessity for the end result to be the rapid and reliable production of a relatively low-technology product.

Current Position and Lessons Learned to Date

The clearest and most outstanding lesson over the last five years has been the need for several years of field experience and testing before being able to move aggressively into the marketplace. The problems of weatherability, high-wind loading, shipping, dealing with roofs and the risk of leaks, flow distribution, toxicity, corrosion, and many more, simply cannot be resolved on the drawing board or after one year of field testing. It is only with the feedback of several years of experience that sufficient confidence can be gained to enter the marketplace with the assurance of doing a creditable job.

The second lesson would be the one of economics mentioned earlier coupled with the need to carefully select the market, gearing the manufacturing of the product such that a very high through-put with very low labor prevails, consistent with reliability. Specifically, we have found that an amortization period of up to five years is acceptable to the customer based on an installed price. Distribution in the consumer market consumes approximately 50% of the gross sales dollar, leaving the manufacturer with the other 50%. Most of the advertising, promotion, development and warranty burdens fall upon the manufacturer, not upon the distribution elements.

We have noticed a tendency in the newly-emerging solar energy industry for people to confuse cost and price. Many people in the industry are talking about the cost of manufacturing collectors and are not acknowledging the great difference between the cost of manufacturing and the price to the consumer, which frequently is a multiple of five. The missing link is the cost of the distribution chain.

Our current production involves a complete heating system primarily designed for swimming pools but with application in hydroponics, aquaculture, and any other low-grade heating application where very low process heat is involved. Our emphasis on a complete heating system has resulted in the development of a number of unique valves, accessories, fittings, and items of hardware specifically designed to do a job which basically has never been done before. The systems emphasis is crucial, as we have found that the development of a single collector means nothing in the marketplace, though it may provide a certain amount of satisfaction in an academic or experimental way.

The all-plastic, monolithic panel has been the cornerstone of our development, as it became clear at the outset that metal and glass and conventional fabrication techniques made for a hopelessly expensive collector when consumer pricing was adjusted to reflect costs of distribution. We have found that plastics still have a lingering bad name resulting from problems in the industry nearly a decade ago, but we feel strongly that plastics are an ideal material for solar panels. Our experience has borne this out.

Conclusions

FAFCO, INC., through its experience over nearly five years is committed to the use of plastics for collector fabrication because of advantages in processing, lack of corrosion, resistance to freezing damage and the very high through-puts possible given properly-designed state of the art production machinery. We have chosen a market which needs a relatively simple collector, is well-concentrated and affluent. We have taken a systems approach and offer a complete package for the heating of swimming pools in recognition of the very high costs of installation which can only be reduced by factory mass production of all of the elements to minimize installation labor. We are selling solar collectors and all the associated inter-connecting and hold-down hardware at a collector price of $2.50 per square foot retail. The field experience over the last five years has been completed by an intensive, accelerated testing both static and dynamic on the mechanical side and by ultra-violet exposure accelerated testing in weatherometers on the chemical side. The surprises of the early years, combined with destructive testing in-house, have lead to a continual upgrading process which lends confidence to our production process, the capacity of which is over 6,000 sq. ft. of collectors per day.

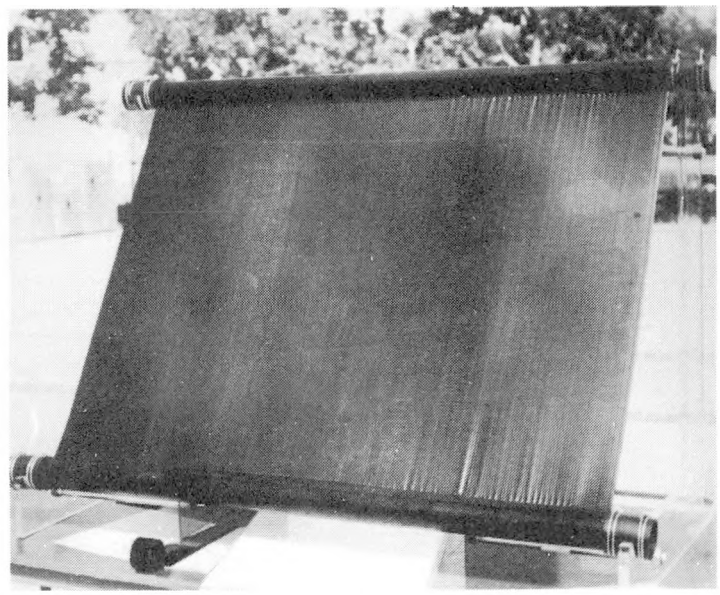


Fig. 1 -- FAFCO Plastic Solar Collector Panel

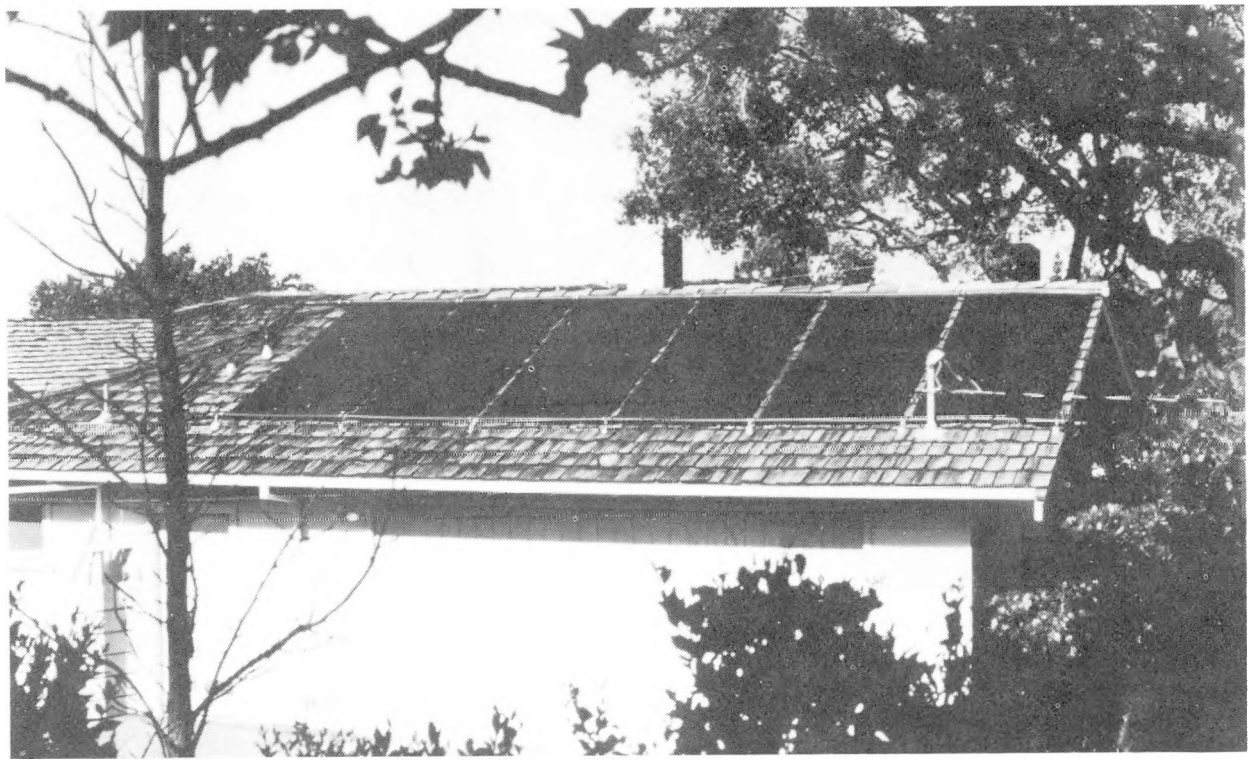


Fig. 2 -- Plastic Collector Panels Mounted on Roof for
Pool Heating Installation

DISCUSSION

Question (William R. Martini, McDonnell Douglas): Do you sell by mail order do-it-yourself kits for the home handyman?

Answer (Freeman A. Ford, FAFCO, Inc.): From the beginning, FAFCO has emphasized a systems approach to the solar heating job and for that reason does not sell panels by themselves, but with interconnecting and hold-down hardware and associated controls to make them work. All of this can be packaged individually for the homeowner, and a significant percentage of our business to date has been directly to the homeowner who has installed the unit himself using our Installation Manual.

Question (Alan S. Hirshberg, Jet Propulsion Laboratory): What is the real expected lifetime of your collectors in a normal environment?

Answer: Extensive, accelerated aging tests, as well as actual field experience, suggest that the life of the FAFCO panel is in excess of 10 years. The most important reason for this is the use of precise quantities of correctly sized, finely dispersed carbon black in the original compounding of the resin. If all plastics could be black and were properly treated, ultraviolet degradation would be of very little significance in the industry. The second reason for the long life of the panels is that the mechanical structure is extremely strong with burst strength in excess of 100 psi at room temperature, while the actual working pressures in a swimming pool application are approximately 6 psi. Problems of corrosion are eliminated by the fact that the polyolefin family of plastics is extremely inert and is not subject to chemical degradation.

Question (Shawn B. Buckley, Massachusetts Institute of Technology): What is the hottest recorded temperature on your swimming pool collectors?

Answer: We have measured surface temperatures on uncovered panels of approximately 150° F. Single-glazing layers of Tedlar-coated fiberglass have yielded skin temperatures in excess of 220° F.

Question (Stephen L. Sargent, University of Maryland): Is there any chance your plastic collector could be used for relatively low-temperature space heating, if you cover it with glass and insulate the back?

Answer: This is not only possible, but is being done, with the major constraint being the need to avoid high temperatures and high pressure simultaneously. The FAFCO panel is designed to take a very high rate of flow with very low head loss in a swimming-pool application; therefore, flows of 1 gal/min or less in the high-temperature applications require something less than 1 psi of dynamic pressure, which means that the collectors can operate in the 200° F range with no danger of mechanical damage. The use of the panels in high-temperature applications is prevalent enough for us to have developed an Applications Note No. 1, which is available upon request.

Question (Mr. Sargent): What kind of plastic and black pigment do you use?

Answer: The plastic used is a copolymer of polypropylene and polyethylene combining the high-temperature and flexural strengths of polypropylene with the resistance to low-temperature cracking of the polyethylene. The pigment used is a finely dispersed carbon black of precise particle size which provides an extremely effective ultraviolet protection when properly compounded. A happy synergy of the higher performance application of the collectors where glazing is involved is that most of the ultraviolet is filtered out, and, therefore, oxidation damage is the only problem, and this has not proven severe.

Question (Unidentified): What is a typical cross-section of your latest design?

Answer: Visualize a top skin of about 25 mils thick, a bottom skin about 25 mils thick, and vertical members connecting the top and bottom. In effect, you have I-beams on about 3/16-in. centers. With the tensile strength of the polymer we are using, around 4,000 psi, sustained room temperatures and pressures of from 30 to 70 psi are no problem. At higher temperatures you would have a materials problem.

Question (Stephen J. Winter, Guam Energy Office): Can your panels be used for hot water generation?

Answer: Yes. We have found that we can run the panels at 220° F, cycling from 5 to 26 psi at 90-sec intervals. The only real limitation of our type of collector is pressure. There is not a corrosion problem, a freezing problem, a strength problem, or an efficiency problem. But there is a temperature-pressure trade-off that we cannot exceed, and the number happens to be 200° F at 5 psi.

52,097

THE REVERE SOLAR ENERGY COLLECTOR

William J. Heidrich
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Revere Copper And Brass Incorporated
Rome, New York 13440

In the development of the Revere Solar Energy Collector, we were concerned, not only with design performance, but also with simple application and adaptability to meet design and installation requirements in both new and existing construction.

Good, reliable materials, familiar to the tradesmen who would be handling and installing them, was another consideration.

Several years ago, Revere introduced its system of laminated copper building panels for construction applications. At that time it was a new concept in the use of copper. It has now become broadly accepted in architectural and building fields, and there exist a large number of installations throughout the country that attest to its quality and practicality.

The system consists of a light-gauge copper sheet, ten thousandths of an inch thick, adhesively bonded to a substrate which is most commonly plywood, although other materials may be used.

Roll-formed copper joint members are applied at the abutting joints of the panels. In the case of exterior applications, particularly roofing, the completed installation provides the quality and appearance of standard sheet copper construction, but at a substantially lower cost. The low cost feature is due to the simple, fast installation that can be achieved with such a system.

Copper-laminated panels have been used for a variety of building applications such as roofs, sidewalls, fascias, mansards and others.

The Revere Solar Energy Collector employs these copper-laminated panels as collector plates. Rectangular copper tubes are secured to the panels by copper clips to assure good contact between the tubes and the copper surface. A conductive sealant is also used between the tubes and the collector plate to provide the highest degree of heat transfer.

Depending on the type of installation, special adapter fittings are available to enable simple connection to conventional round copper water tubes

that are most commonly used for distribution piping. In other applications it is more expedient to provide individual collectors with the ends of the rectangular tubes brazed directly into the round tube headers.

For new construction applications, a special roll-formed copper solar batten is used to accommodate glass or other transparent covering materials.

This system has been under test at Revere's Research And Development Center at Rome, New York for nearly two years. The results show that the system Revere is marketing today and which is described in its literature will provide for the collection and transfer of the sun's energy in amounts sufficient for various heating and cooling applications.

Continuing development and investigative work are underway to broaden the adaptability of the Revere Solar Energy Collector to various heating conditions or requirements.

One of the main features of the Revere Solar Energy Collector is that it is all copper, with all that metal's well-known inherent qualities and advantages. Another is the capability of varying the manner in which some of the component parts are used. Different tube spacings can be provided as desired or required. Tube passes can be arranged in patterns such as grid, sinuous, or a combination grid-sinuous, to best serve each individual case.

Different numbers of thicknesses of transparent coverings can also be employed.

The features of the Revere Solar Energy Collector are being utilized on the Decade 80 Solar House which is currently under construction in Tucson,Arizona. This house is being built by the Copper Development Association to demonstrate advanced designs for improving the quality of life through the application of solar energy. The solar energy system will provide for heating, cooling, heating domestic hot water and also the swimming pool.

This residence, with 3,200 square feet of living space, will demonstrate a totally integrated solar collector and roof system capable of erection in the normal course of construction, with the skills of today's tradesmen.

The roof facing south utilizes 1,800 square feet of Revere Solar Energy Collector; the roof facing north is of standard Revere copper-laminated building panels. It is expected that about 75 percent of the cooling, and nearly 100 percent of the heating requirements will be provided this residence by solar energy.

The architectural firm of Tanaguchi Associates, Boulder, Colorado, has several current projects in which they plan to use a Revere Solar Energy Collector. One is a residence to be built in Colorado. Another is a condominium to be built at Copper Mountain, also in Colorado. The condominium will utilize approximately 10,800 square feet of the Revere Solar Energy Collector in combination with a heat pump.

Copper tubes and sheet represent the materials of choice for solar collector

panels used in rooftop systems in various parts of the world for water heating. Copper has a combination of thermal properties, ease of fabrication, resistance to corrosion, and long service life that has been proven over many, many years of use.

Revere's Solar Energy Collector is now available in two forms: the combination roof and collector system particularly intended for new construction, and a modular unit for either new or existing construction.

Copies of Revere's manual describing its system and use are available to you after this session.

Thank you Mr. Chairman.

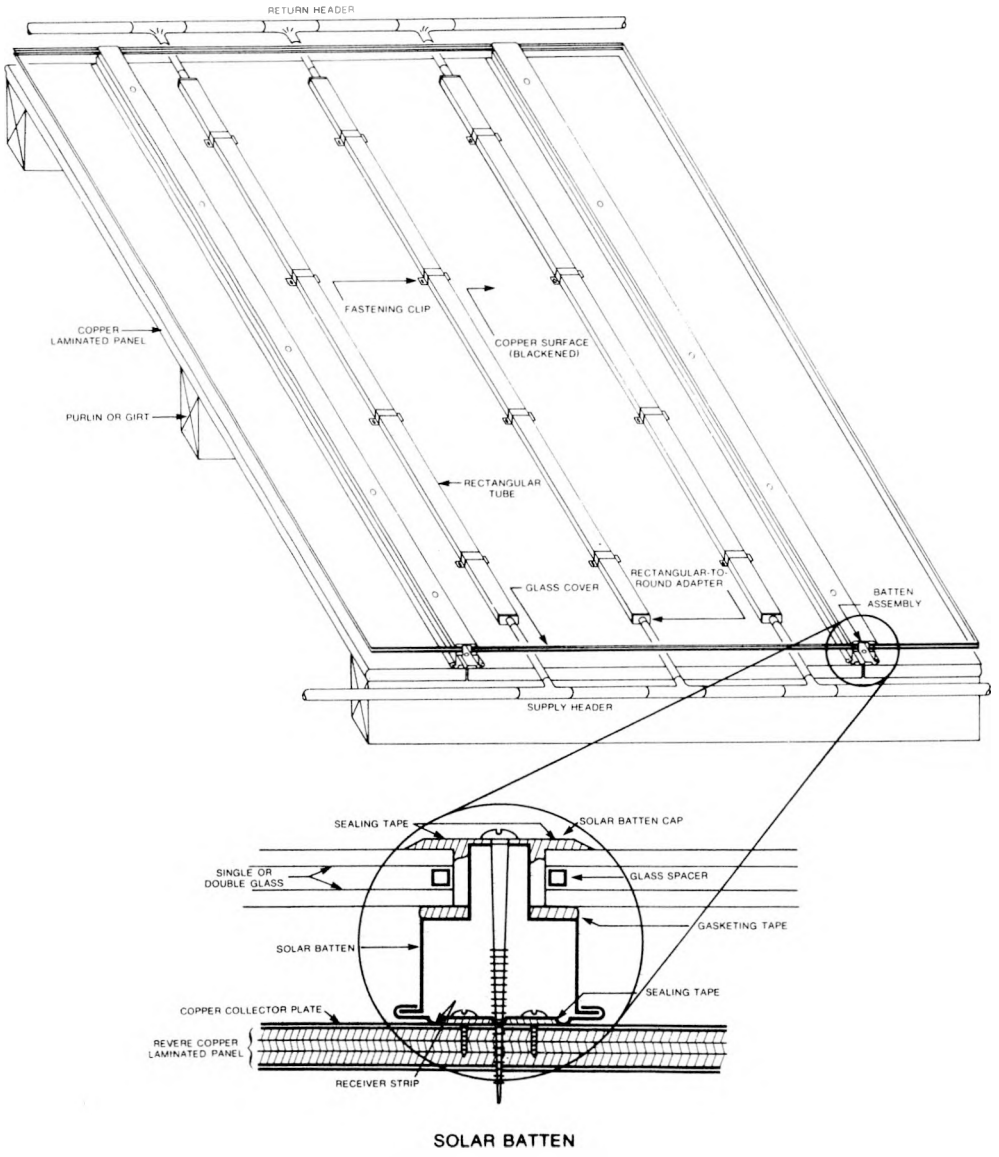


Fig. 1 — Diagram of Revere Solar Collector Panel

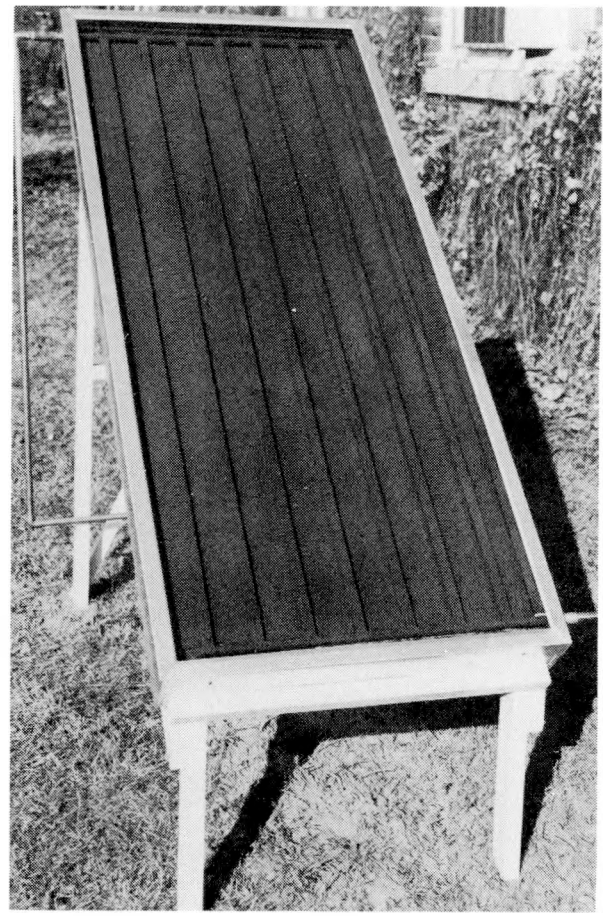


Fig. 2 — Revere Modular Solar Collector Panel Under Test

DISCUSSION

Question (George B. Cain, Copper Development Association, Inc.): Will widespread use of copper collectors seriously affect the U.S. copper resources?

Answer (William J. Heidrich, Revere Copper and Brass Incorporated): Present Government figures indicate copper reserves and resources total 366 billion pounds. There are approximately 3½ billion pounds of copper mined in this country each year, and an almost equal amount recycled from scrap materials. Construction applications in this country use about 1½ billion pounds of copper each year. If we assume an average requirement of copper for a solar collector on a residence to be about 400 pounds, even if a million homes per year used solar energy, which is highly unlikely, the impact on the supply of copper would be virtually unnoticeable.

Question (Roy A. Lawrence, Ohio University): What is the price of your product?

Answer: $7.80 per square foot f.o.b. Rome, N.Y., for the complete modular unit, and $5.90 per square foot f.o.b. Rome, N.Y., for the new construction unit. Glass is not supplied with the new construction unit, since this is a field installation and the glass can be obtained locally more economically.

Question (Bruce N. Anderson, Total Environmental Action): What would Decade 80 cost if it were not a prototype?

Answer: I can only guess that it would be in the $125,000-$150,000 range.

Question (Mr. Anderson): Do you think that it is moral to promote a home of this size, which consumes such enormous quantities of materials and energy in its construction and operation?

Answer: I think it is moral, proper, and desirable for future progress that projects such as this be undertaken. While the Decade 80 house is somewhat larger and more expensive than the average house being built today, in my opinion it *did not* consume either enormous or even unusual quantities of materials and energy in its construction. It should be recognized, too, it is through projects such as this that the practicability of new ideas and new uses of materials are established that eventually lead to the lower costs that exist in the larger segment of the home-building industry.

Question (Mr. Anderson): What is being done to eliminate absorber-plate deterioration (delamination of the copper from the plywood) at temperatures over 200° F? How can you justify promoting this product until this is solved?

Answer: The plywood portion of the copper-laminated panel is only a vehicle for getting the copper collector plate and tubes in place in the collector assembly. The plywood has no influence whatever on the performance or heat output of the collector plate whether or not delamination occurs. The 6-in. spacing of the tubes and the use of clips to secure the tubes to the collector plate assembly provide for good, continuous contact between the copper tubes and the collector plate, which is the important factor, even if complete delamination should occur.

Question (Salem O. Kabawi, Libyan Atomic Energy Commission): It was mentioned that copper is very expensive. You said that your collector is cheap and efficient. Could you comment on this?

Answer: Copper is termed an expensive material by those unfamiliar with both metal markets and metal uses. It is true that copper costs more per pound than some other metals, say aluminum or steel, but because of its superior heat-transfer characteristics, lighter or thinner collectors of copper can be used to provide the same output performance as with other metals. Copper also has unmatched corrosion-resistant and maintenance-free qualities that offer longer life than other materials. Understanding the advantages and features that copper offers and properly integrating them into the design of solar collectors yields a product that is efficient and competitive with those made of other materials that might have a lower per pound cost.

SESSION 5

COLLECTOR MATERIALS AND COMPONENTS

CORROSION PROTECTION FOR ALUMINUM SOLAR ENERGY COLLECTOR PLATES

S. H. Butt
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Olin Corporation
East Alton, Illinois

Precautions should be taken to maximize the corrosion resistance of solar energy collector plates which operate with a water-base heat transfer fluid. The following suggestions and discussion are offered for consideration by the user. "Typical" solar energy collector systems are "multi-metal" systems in which water-based heat transfer fluid circulates not only through aluminum but also through other metals.

Specific operating experience with solar energy collectors in multi-metal systems is limited. They may be compared with automotive cooling systems, particularly those in which an aluminum radiator or an aluminum block or aluminum head are used. These systems operate successfully. They are multi-metal systems. The heat transfer fluid (water-antifreeze mixture) circulates not only through aluminum (the aluminum radiator or the aluminum block) but generally also circulates through steel components, copper and brass components and comes in contact with soft solder used in the joining of copper and brass components. The coolant used in this type of automobile system is a water-ethylene glycol mixture and the ethylene glycol contains various inhibitors and buffers which are intended to make it compatible with the multi-metal cooling system. In the case of General Motors' vehicles, it is our understanding that the coolant is made to their Specification GM-1899-M, "Antifreeze Concentrate – Ethylene Glycol Type."

Ethylene glycol degrades in automotive service and organic acids form. Since a significant reduction in pH, which could accompany the formation of the organic acids, would serve to make the mixture more corrosive, one function of the buffers used in automotive antifreeze formulations is to control pH. When and if the buffers are exhausted, pH may drop. Thus, the usual recommendation of the automobile manufacturer for periodic replacement of the coolant mixture.

The frequency with which an ethylene glycol-water heat transfer fluid must be replaced in solar collector service will depend upon the design and operating characteristics of the system. The operating temperatures typical of most solar collectors tend to be somewhat lower than automobile cooling system operating temperatures. On the other hand, the total operating time to be expected of a solar collector during a calendar year is undoubtedly greater than is normal for an automobile cooling system. This suggests that, until such time as the system manufacturer and his customers have gained sufficient experience with a specific system to predict heat transfer fluid life, provisions be made for monitoring pH of the solution so that it may be changed when necessary. It is suggested that the recommendations of the antifreeze manufacturer be sought as to the pH range to maintain.

The usual automotive coolant mixture uses ordinary "tap water." The composition and corrosivity of tap water varies quite widely. The corrosivity of the tap water used may be a factor in the corrosion performance of the automobile multi-metal system. The variable of possibly unsuitable "tap water" may be avoided through the use of distilled and/or deionized water with commercial ethylene glycol antifreeze. This appears to be a worthwhile and not too costly precaution.

In some collector systems, antifreeze is not used. In these applications, it will be necessary to treat the water in order to insure the integrity of the protective oxide films. Untreated water should not be used in aluminum collector systems. Various types of inhibitors are available and instructions for their use can be obtained from the manufacturer. Chromate inhibitors are popular and perform admirably in service.

A typical solution would be 500 ppm chromate made up as follows:

0.9 gpl	$Na_2CrO_4 \cdot 10H_2O$	(.120 oz. per gal.	$Na_2CrO_4 \cdot 10H_2O$)
0.082 gpl	$Na_2Cr_2O_7 \cdot 2H_2O$	(.011 oz. per gal.	$Na_2Cr_2O_7 \cdot 2H_2O$)

The powders are dry mixed and dissolved in approximately twice the weight of water. This solution can then be added to the storage tank. The pH should be between 6 and 7. The inhibitor level should be maintained at 500 ppm chromate. Glass phials of chromate solutions containing known amounts of chromate could be used to check the level in the system on a color comparison basis. The pH level is important in color determination and should be kept within a range of 6 to 7.

A word of caution: Chromate inhibitors should not be considered for use with water-antifreeze mixtures.

Aluminum components in the system should be galvanically isolated from components made from other metals.

The use of a "getter" column, through which the heat exchange fluid circulates before entry into the aluminum portion of the system, has been suggested. Such a "getter" column would consist of a plastic cylinder containing a series of aluminum sheets or an aluminum screen. The water would circulate over this surface and the function of the surface would be to pick up "heavy metal" ions which may have gotten into the system as the result of corrosion of other metal components or as the result of "tramp" material within the system.

It is desirable that heat transfer fluid design velocity through the system be limited to two to three feet per second.

Although we understand that normal operating temperatures for most solar energy collectors will be below 212°F, we must also consider the possibly higher temperatures which will be encountered during shutdown of the collector system. Collector systems intended to provide space heating only will be shut down in the summer months. Further, systems intended for use in providing both space heating and domestic hot water heating will operate only intermittently during the summer months because of reduced heat demand. A survey of current literature indicates that, under shutdown conditions (no flow of heat transfer fluid) and at times of high ambient temperature, collector temperatures may reach 300°F or more. Further, degradation of the chlorinated and/or fluorinated hydrocarbons, which appear to be widely used in "blowing" organic foams, may also occur at these temperatures. The potential degradation products include hydrochloric acid (HC1) and hydrofluoric acid (HF), both of which are highly corrosive to all common metals, including aluminum. Therefore, we suggest that the use of foamed plastic insulation on solar collector plates be avoided.

As indicated above, these suggestions are offered for the consideration of the system manufacturer or system user and are intended to help to optimize the corrosion per-

formance of aluminum components in the system. There is substantial diversity of system design and this may introduce other factors which ultimately affect corrosion performance. Each individual system should be evaluated to determine the mode of corrosion protection which is most appropriate to it.

DISCUSSION

Question (Richard E. Stephens, Tampa Electric Co.): I understand that some of the larger companies have done research on nontoxic fluids for flat-plate collectors. Can you shed any light on the state of development and availability?

Answer (Sheldon H. Butt, Olin Brass Corporation): Of course, untreated water that is not toxic can be used with copper or copper alloy collectors. Water-base heat-transfer fluid systems used with aluminum collectors must contain corrosion inhibitors. All of these are to some degree toxic, although the degree of toxicity varies. As an alternative to water-base systems, the "Dowtherms" and high-molecular-weight fluorinated hydrocarbons (Freons) have been used. I do not know precisely how these organic fluids rate in terms of toxicity, and suggest that detailed information can be obtained from the manufacturers of these fluids, such as the Dow Chemical Company and E. I. du Pont.

It should be noted that the heat-transfer performance of the organic heat-transfer fluids is substantially inferior to that of water. This disadvantage may be offset through the use of more closely spaced tubes in the collector plate in order to increase the ratio of wetted area to total area.

Question (Robert L. Reid, University of Tennessee): Are the inhibitors toxic? If yes, is the toxicity high enough to require double-wall heat exchangers to meet code requirements?

Answer: As indicated in the answer to the preceding question, all of the inhibitors are in some degree toxic. It is my understanding that the level of toxicity permitted without requirement for double-walled heat exchangers or other devices for isolating the fluid from potable water varies in individual code jurisdictions. It is possible that inhibitor systems, such as phosphate-borate mixtures, might be acceptable. However, this would have to be checked with the individual code authority.

Question (Paul Curto, University of Maryland/Armstrong Associates): What is the maximum safe operating temperature (200°-400° F) and pressure under which the aluminum Roll-Bond® can be operated for long life (10-20 years) in collector applications? What inhibitors and/or corrosion additives remain effective at elevated temperatures? What percentage of the contact surface is completely bonded in the diffusion bond process?

Answer: The size and shape of the tubular passages in Roll-Bond® can be varied. The thickness of the material can also be varied. Relatively small diameter, approximately cylindrical, tubes in thick Roll-Bond® can withstand much higher pressures than large flat-sided tubes in thinner material. Thus, there is no single answer to the question. The material used is 1100 aluminum. In general, because of inferior corrosion characteristics, the relatively high strength aluminum alloys cannot be used; and in addition, there are some of these that do not bond satisfactorily. Data regarding the strength of aluminum 1100 at various temperatures is available and can be used by the designer to calculate maximum pressures that can be tolerated at various specified temperatures in a specific design. We will be happy to help with specific design calculations.

It should be noted that, even under optimum design conditions, the pressure limitations at rather high temperatures, such as 400° F, will be quite low since at this temperature the creep and stress rupture strength of 1100 aluminum is low. For high-temperature/high-pressure collector applications, the designer may wish to consider the use of copper alloy Roll-Bond®. High-strength/high-conductivity copper alloys are available that will provide substantial strength at temperatures of 400° F and above.

Commercial antifreeze formulations are normally intended for operation at temperatures up to approximately 245° F. As the temperature increases, the rate at which ethylene glycol decomposes to an organic acid will increase. Thus, prolonged high-temperature operation will shorten the life of water-antifreeze mixtures. In general, the inhibitors and buffers used in these mixtures are inorganic compounds that are stable at elevated temperature. Most of the inhibitor systems that can be used with water (without antifreeze) are also stable inorganics. In general, the most severe corrosive conditions in aqueous systems occur at temperatures below the

boiling point, since the presence of dissolved oxygen in water increases its corrosivity. Exposure to steam at relatively elevated temperature, as may occur in the case of a collector that is pressure vented or that reaches elevated temperature under "stagnation" conditions, may actually be beneficial through the formation of a Boehmite film on the interior surface.

The Roll-Bond® process is, in effect, a forge-welding process in which two sheets of metal are bonded together in all areas except those areas which are later inflated to form tubular passages. Essentially a 100-percent bond is obtained everywhere else, and it is normally not possible to identify the original interface between the two starting sheets metallographically after processing has been completed. The inflation process itself uses high-pressure air. In practice, any poorly bonded areas adjacent to the inflated pattern will show up during the inflation process as "peelers." This is cause for rejection. Thus, the inflation process provides a mechanism for inspecting bond integrity.

Question (Kenneth H. Speiser, Grumman–Energy Program): Could you please amplify on your statement regarding a getter for corrosion control?

Answer: In an aqueous environment, ions of metals that are more "noble" than the collector material will deposit galvanically upon the surface of the collector material. Most of the "heavy" metals are more noble than aluminum. Localized galvanic corrosion will occur at these sites and, unless arrested, may continue until deep pitting and perforation of the collector has taken place. One of the major functions of the inhibitors used in aqueous heat-transfer fluids is to inhibit corrosion of the heavy metals in the system, and thus prevent ions of these metals going into solution.

The purpose of the "getter" is to provide a second line of defense by acting as an "ion trap" to trap heavy metal ions which might have gotten into solution despite the use of an inhibitor. In the case of an aluminum collector, aluminum is placed in the heat-transfer circuit between the possible source of heavy metal ions and the collector so that the heavy metal ions will be picked up by the aluminum in the "getter."

Typically, a getter would consist of a plastic tube or container containing a multiplicity of thin aluminum sheets or a coil of aluminum screen, etc. The purpose is to allow the heat-transfer fluid that may contain heavy metal ions to contact the aluminum in the getter. It is suggested that the design be such that the "dwell time" within the getter is on the order of 30 seconds.

Question (Herman G. Barkmann, Barkmann Engineering): What commercial pacifiers for aluminum are available? Is the pacification in commercial antifreeze (Prestone) adequate for aluminum collectors?

Answer: The text of the paper answers these questions in part. There are other inhibitors available besides those described in the paper. Their suitability will depend somewhat upon specific operating conditions and system design, and it is recommended that a water treatment consultant be contacted for recommendations relating specifically to each individual design and set of conditions. Some commercial automotive antifreeze formulations are suitable for use with aluminum Roll-Bond® collectors, others are not. The paper calls out one formulation that is. The manufacturer of the antifreeze should be contacted as to the suitability of his product for use in a multimetal system containing aluminum. We believe that those antifreeze formulations which contain particles that are intended to plug leaks in automotive cooling systems should *not* be used in solar collectors. Fluid velocities in solar collector systems may be quite low as compared to velocities in automotive cooling systems. Under such conditions, the particulate matter used in some antifreeze formulations may settle out at points of low fluid velocity and create conditions that would be conducive to crevice corrosion.

Question (Richard LaRosa, Hazeltine Corp.): What pH should be used with aluminum/antifreeze? Is ethylene glycol an alcohol?

Answer: The recommended pH range is 6 to 7. Technically, ethylene glycol is an alcohol, and its correct name is 1,2-Ethanediol.

Question (Richard L. Field, USN Civil Engineering Laboratory): Does the common household water softener give sufficiently deionized water to use with an aluminum collector?

Answer: No. Most household water softeners are intended primarily to "soften" water by exchanging sodium ions for dissolved calcium ions. In the case of a "hard" water, this is desirable and may even be necessary to prevent formation of calcium carbonate scale at elevated temperature within the fluid passages in the collector. However, the further purposes of deionization of the aqueous fluid in a collector system are to remove heavy metal cations that could otherwise deposit upon the aluminum surface and cause galvanic corrosion, as well as to remove undesirable anions, such as halogens, since their presence in the water increases its corrosivity.

It is suggested that the advice of a water treatment consultant be solicited to define the proper treatment for specific water sources. Of course, an alternative is the use of distilled water.

52,099

INTERMETALLIC ABSORPTION SURFACE - MATERIAL SYSTEMS FOR COLLECTOR PLATES

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Attleboro, Mass. 02703

The objective of this project is to develop a composite metal solar collector plate in which an intermetallic absorption surface is integrally combined with a tube-in-sheet collector plate. The goal for the intermetallic absorption surface is solar absorptance $\alpha>0.9$ and the infrared emittance $\varepsilon<0.3$. The goal for the tube-in-sheet collector plate development is to use the composite metals technology to combine materials and use them in quantities and locations which assure the best corrosion resistance and the most economic use of materials.

Intermetallic compounds, such as Fe_2Al_5, have a highly porous surface structure when they are formed by reacting the component metal layers thermally in solid state, Figures 1 and 2. If the dimensions of the pore structure are of the same order as the wave length of solar radiation, these surfaces absorb as black body cavities, but radiate in the infrared wave length region as flat surfaces. Surface shown in Figure 1 has $\alpha=0.955$ and $\varepsilon=0.78$. The absorptance and emittance of the intermetallic compound surface are affected by factors like stoichiometry, presence of surface oxides, and the compound forming conditions.

To evaluate the effect of the composition, specimens were prepared with aluminum as one component and low carbon steel, 304 and 430 stainless steels, nickel, and copper as the other component. As an addition to the materials, the effect of the aluminum thickness and the atmosphere during the compounding heat treatment was evaluated. Table 1 lists the best results for each material system. The aluminum-copper pair could not be compounded to form an acceptable surface morphology because of the low melting eutectic formed by this binary system. The results also indicate that addition of chromium and nickel as alloying elements into iron, in quantities they are used for 430 and 304 stainless steels, does not significantly alter the solar absorptance or infrared emittance characteristics of the aluminum-iron material system.

Aluminum-nickel compounds exhibited the highest solar absorptance and also the highest α/ε ratio; therefore, the system was selected for optimization studies. The effects of the thickness of the aluminum layer and the temperature, atmosphere, and time of the compounding heat treatment were evaluated. Preliminary results show that

with the Al-Ni system it is possible to obtain $\alpha \sim 0.99$ and corresponding $\varepsilon \sim .27$. This also represents the best α/ε ratio of 3.7. Typical values, obtained under broader compounding conditions, are $\alpha \sim 0.95$ and $\varepsilon \sim 0.3$. The actual composition of the intermetallic compound has not yet been determined, but because the highest α values were obtained with specimens compounded at the lowest temperatures, it is assumed that the most desirable surface morphology is formed by the $NiAl_3$.

The flat plate solar collector is a unique construction material, which is exposed in most designs to atmospheric, aqueous corrosion, and severe thermal cycling. Therefore, it is not surprising that most of the reported performance problems with flat plate collectors are related to various forms of corrosion. A special emphasis in this program is to design a composite material system to minimize corrosion and to test the developed materials for their durability under normal operating conditions. Accelerated tests will be used for screening purposes.

Composite material technology offers an unique opportunity to combine materials with differing characteristics and unit cost to achieve the desired collector plate properties such as high thermal transfer between the absorption surface and the heat transfer fluid, corrosion resistance, strength, low weight, and low cost. Figure 3 shows a segment of tube-in-sheet collector plate in which low carbon steel is used as a low cost structural material and 0.004" thick copper is used as the heat transfer fluid channel liner. The steel assures high strength and adequate heat transfer characteristics and the copper lining makes the collector plate compatible with the rest of the solar collector system plumbing fabricated, in most cases, from copper. Further work is required to optimize the system, and as an example, 90/10 cupro-nickel can be used instead of copper, or properly designed barrier layers can be used instead of more noble metal linings.

Facilities have been completed to test dry intermetallic absorption surface samples for the atmospheric corrosion characteristics and thermal stability in typical flat plate collector design. However, the most important part is to test the integrated collector surface/tube-in-sheet material system under actual collector conditions to determine the thermal performance and the durabilities of the absorption surface and the tube-in-sheet structure. For this purpose, a 16 sq. ft. collector is under construction in which 16 separate samples can be evaluated simultaneously.

TABLE I - Solar Absorptance and Infrared Emittance of Selected Intermetallic Compound Surfaces

Material Pair for Compounding	α_{solar}	$\varepsilon_{3-30\mu}$	α/ε
Aluminum - Low Carbon Steel	0.99	0.55	1.8
Aluminum - 304 Stainless Steel	0.89	0.47	1.9
Aluminum - 430 Stainless Steel	0.98	0.51	1.9
Aluminum - Nickel	0.94	0.30	3.1

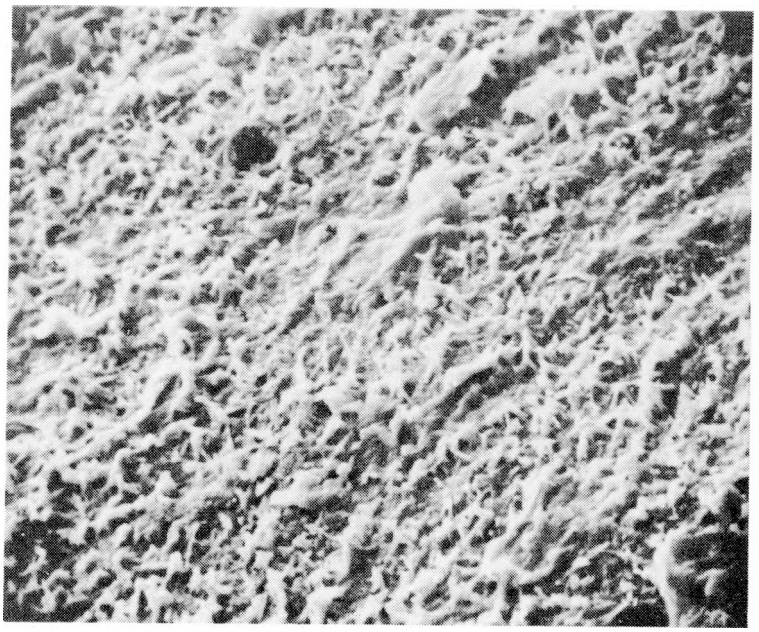


Fig. 1 – Scanning Electron Microscope Picture of Fe_2Al_5 Intermetallic Compound Surface

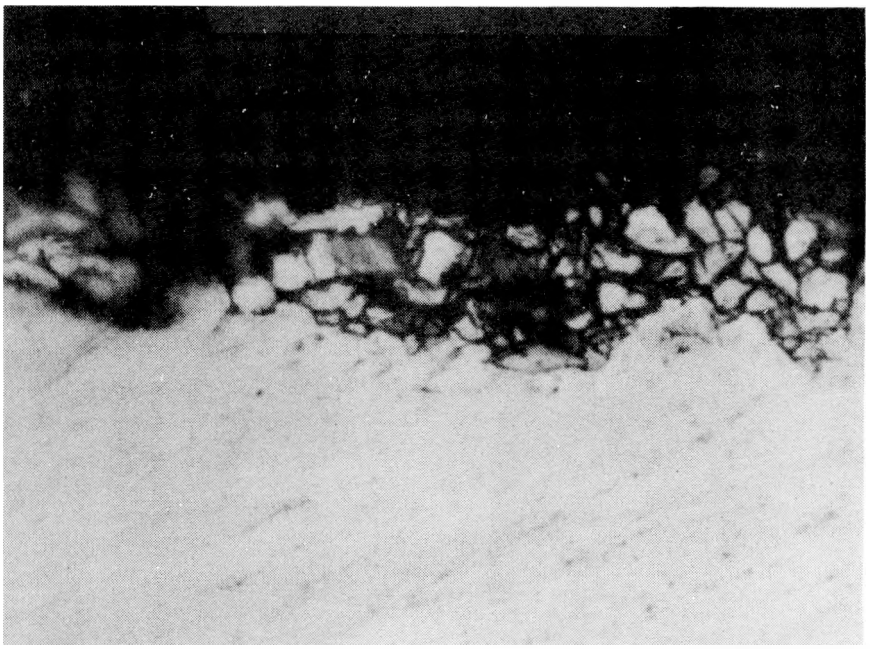


Fig. 2 – Cross Section of Fe_2Al_5 Intermetallic Compound Surface

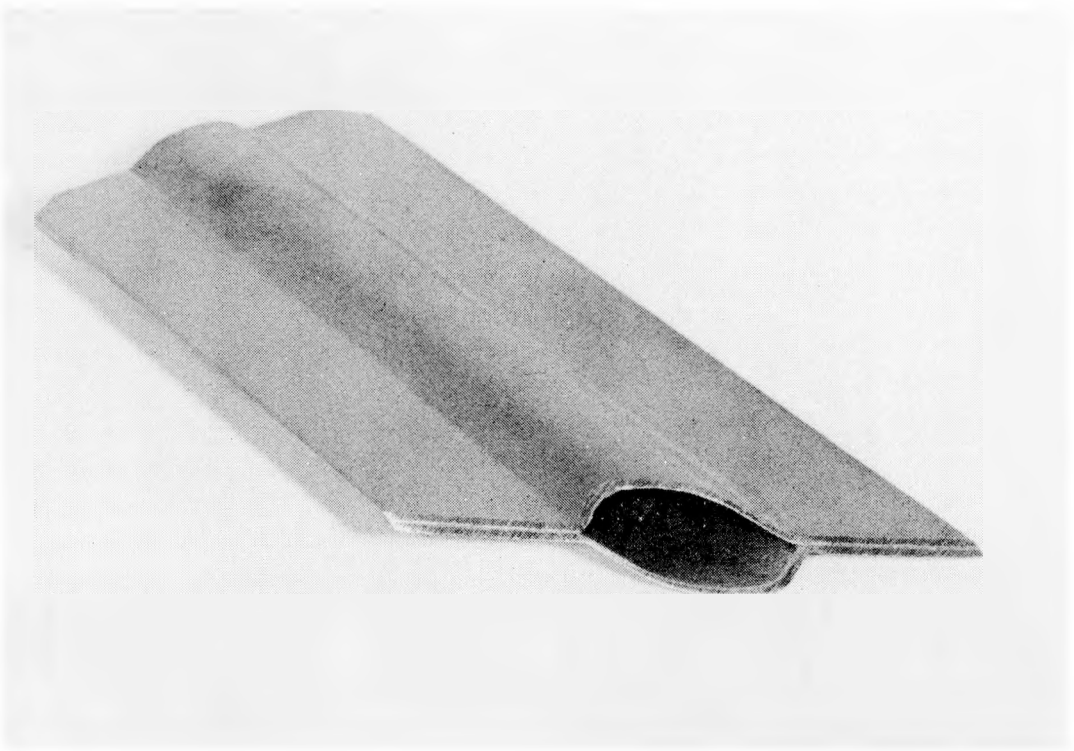


Fig. 3 – Section of Low-Carbon Steel/Copper Composite Metal Tube-in-Sheet Structure. The Copper Heat Transfer Fluid Channel Liner Shows as the Light Colored Line in the Cross Section

52,100

TITLE: OPTICAL COATINGS FOR FLAT PLATE SOLAR COLLECTORS

CONTRACT NO.: NSF-C-957

PROGRAM MONITOR: Harold Horowitz, NSF

PRINCIPAL INVESTIGATOR: Henry Mar, Honeywell, Inc.

SUMMARY

This program started 15 September 1974. The purpose of the program is to investigate coatings which will enhance the performance and economic feasibility of flat plate collectors. The primary coatings of interest are electro-chemical and paint type solar absorber coatings and chemically etched antireflection coatings.

ELECTRO-CHEMICAL COATINGS

Electro-chemical coatings have good optical efficiency (solar absorptance $\alpha \approx 0.9$ and room temperature emittance $\epsilon \approx 0.1$) and relatively low cost (compared to vacuum deposited coatings). However their long term environmental stability is unknown. We are attempting to identify the coatings with the best stability and will then optimize those coatings with respect to optical performance and cost.

Currently, the following coatings are under consideration: black chrome (chromium oxide), black nickel (Ni-Zn-S), black copper (copper oxide), iron oxide, and a potassium permanganate treatment for aluminum. Substrates being studied are: steel, copper, galvanized steel, aluminum, and several nickel plated metals. The effects of exposure to high temperatures, humidity, abrasion, and ultra-violet light are being measured. To date, black chrome coatings on nickel plate have displayed the best overall combination of durability and optical properties ($\alpha \approx .96$ and $\epsilon \approx .10$). Black nickel coatings show the best optical properties ($\alpha \approx .96$ and $\epsilon \approx 0.06$) but variable durability. The use of organic overcoats to improve humidity resistance and solar absorption is also under consideration.

PAINT COATINGS

A selective paint offers the potential advantages of ease of fabrication and application, durability and repairability. However, it is not known if a paint can be made with suitable optical properties.

Currently an intensive search is being conducted to identify pigments and binders suitable for a selective paint. Candidate pigment materials identified to-date include Bi_2S_3, CdTe, CuS, Ge, PbS and Si. The most promising binders

identified to-date are the aliphatic polymers. These include polyethylene, polypropylene, polyisoprene and polyamide polymers. A 30 PVC, 1 mil thick, CdTe/polypropylene coating has been formulated with $\alpha = 0.85$ and $\epsilon = 0.65$. Coatings of PbS in polypropylene and Bi_2S_3 in polypropylene are being formulated.

ETCHED COATINGS

Glass can be etched by immersing in a silica supersaturated hydrofluosilicic acid bath of controlled composition and temperature. The acid attacks the glass surface and produces a porous silica layer which has an effective refractive index between that of glass and air. This porous silica layer thus constitutes the anti-reflection coating. With such a coating we have successfully reduced the two-surface reflection loss from the original 8 percent to less than 2 percent (in the solar spectrum).

Currently three areas of concern are under investigation: 1) coating durability; 2) etching solution control; 3) process scale-up. With respect to durability we have found that dirt and oil can be easily cleaned off with restoration of high transmission. Tests are under way to determine the effects of long term weathering. Abrasion resistance is a serious problem. Initial coating could be removed by vigorous rubbing with a finger. Current coatings now pass the cheese-cloth rub test (MIL-M-135083) but do not pass the eraser rub test (MIL-C-675A). With respect to solution control we have found that chemical control of the etching solution is critical. Solution composition, especially the degree of supersaturation, drifts as samples are etched and as components evaporate. This causes non-uniformity from sample to sample. Methods to control the solution composition are being investigated. With respect to process scale-up we have previously found that a solution sample taken from a large tank (3' x 8' panes) could be successfully used in the laboratory (2" x 2" samples) while that same solution in the large tank would not work. Current work with intermediate size tanks (2' x 2' panes) indicates that temperature and solution uniformity are key parameters in process scale-up.

We also plan to investigate the antireflection coating of Tedlar. The first approach will be to search for solutions which attack Tedlar and leave a porous surface as in the glass etch process. The second approach will be to coat the Tedlar with an adherent polymer to which a leachable dopant has been added.

DISCUSSION

Comment (Steven M. Ridenour, Dubin-Mindell-Bloome): It would seem that high α/ϵ ratios (10 to 20) are significant for collector thermal performance only when α is high (90 to 95). Please comment.

Reply (Jaan Jurisson, Honeywell Systems and Research Center): Our objective with black nickel and black chromium absorber coatings has been to improve their respective α's. Our current α's are between 0.95 and 0.96 for both types of coatings.

Question (Unidentified): Some black chrome coatings have a "cutoff" in the solar region, so that the α/ϵ ratio doesn't mean a great deal. Do you know what the optical curve of the chrome you are evaluating looks like? If so, is there a cutoff around 2 microns?

Answer: The only differences we have observed between black nickel and black chromium are in their respective ϵ's. Nominal ϵ values for black nickel and black chromium are approximately 0.07 and 0.12, respectively. Black chromium is more durable, however.

Question (Unidentified): Nickel and chrome selective coatings that are electrodeposited have been predicted to cost around \$5 per ft^2 under production conditions (with OSHA and EPA requirements). Do you believe the coatings you are evaluating will cost any less, or significantly less?

Answer: The cost of application depends to great extent on the substrate material. On steel the application cost should be less than half of \$5 per ft^2.

EXPERIMENTAL RADIATIVE PERFORMANCE OF MODERATELY CONCENTRATING SOLAR COLLECTORS

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Introduction

This work is sponsored by NSF/RANN Grant GI-41003 at the University of Houston. Under a cooperative agreement, some experimental measurements are being carried out at the Johnson Space Center. We are at the mid-point of the one year grant.

The paper by Dr. Richard Bannerot (Session 6) describes fully the basic concept of the collectors being designed. The idea is to use reflecting surfaces of optimal geometry within the solar collector tray to allow increased collection temperatures at reasonable collector efficiencies. The particular geometry presently under study consists of trapezoidal grooves with mirrored sidewalls and an absorbing base. The grooves are aligned in an East-West orientation. Dr. Bannerot's paper describes the analytical prediction of the behavior of this type of collector.

This paper is concerned with the experimental verification of the computer analysis. If the comparison is valid, then the much less expensive computer predictions can be used for further optimization of the geometry.

Experimental Equipment

The basis of the experimental measurements reported here are a source of visible radiation providing near-solar spectral distribution, and a detector matched to this spectrum. The particular solar simulator used is an Aerospace Controls Corporation Model 302+, which provides a uniform square field of solar energy. When the field is adjusted to give a one-foot square, the flux level provided is equal to one sun (Fig. 1).

For a detector, a Photo Research Corporation Pritchard photometer Model 1970-PR is used. This instrument allows view of a field adjustable from 15 minutes of arc up to fields of 5^{o} by use of replaceable apertures (Fig. 2).

In operation, the source is made incident on the collector model to be examined. A diffusely reflecting small disk of very high reflectivity is placed at the measurement point on the model. The photometer is then focused on the disk so that

the aperture is covered by the view of the disk. The photometer reading is then proportional to the energy incident on the disk from all sources; i.e., both directly from the simulator and from simulator energy reflected by other parts of the model. The laboratory where measurements are made is painted black, and all lights with the exception of the source are extinguished during measurements. This is necessary because the measurement system is not chopped to eliminate background radiation.

For our tests, a model was constructed to allow testing of various groove geometries (Fig. 3). The wall angle and base width are adjustable, and end mirrors make the model optically equivalent to an infinitely long groove. The reflecting surfaces are removable so that various materials can be tested. The best performance is obtained with mirrors, with considerable degradation when materials such as aluminum foil on a fibreboard backing are substituted. Cost is the chief factor in determining the material selection.

In practice, two diffuse disks are used. The measurement disk is placed on the base surface of the groove. The second reference disk is placed outside the groove at the same distance from the source and is used to determine incident flux. The solar source is then made incident on the model. The model orientation can be changed to allow various angles of solar incidence. The photometer reading gives the flux incident upon the disk due both to direct incident flux and reflection from the sidewalls. When this reading is referenced to the direct flux from the source, the result is the concentration ratio of the geometry being tested. Corrections are made for the slight non-diffuse reflection characteristics of the disk where necessary.

Only the radiative behavior of the collectors is provided by these tests. Further tests using flow and temperature measurements are of course necessary for complete evaluation of the collectors.

Results

For comparison of the analytical and experimental results, certain properties of the model materials must be input to the computer program. These properties were measured independently, and the computer results generated for comparison with the experiment. Of major significance and effect, in addition to the model geometry and sun angle, is the behavior of the reflecting sidewalls. Two parameters affect the reflection; these parameters are the solar absorptivity of the sidewall, α_{sw} and the fraction of incident energy reflected specularly (as for a perfect mirror), f. The computer model assumes that reflection occurs either specularly or diffusely, and the input f gives the relative amount of each.

In Figs. 4 and 5 are presented results for the concentration ratio attainable for two geometries as a function of noon-

time sun angle. The experimental results were obtained using back-surfaced 1/4 inch thick plexiglass mirrors for the reflecting sidewalls. The solar absorptivity of these materials was found to be relatively high, near $\alpha_{sw} = 0.2$. The mirrors are of course quite good specular reflectors, so that f is near 1.0. Computer results for f = 0.9 and 1.0 are shown for illustration.

Work is continuing to determine the best geometry and materials to allow high concentration ratio over the daily and seasonal variations of sun angle. Because of the good agreement found between analysis and experiment, computer optimization is being pursued.

A full-size working collector is under construction using concentrators of optimum design. A spectrally selective coating on the base absorber and the partial suppression of free-convection by the cavity shape (when cover glasses are added) give predictions of outstanding collector performance. The collector will be tested at the NASA Lewis Research Center Solar Test Facility.

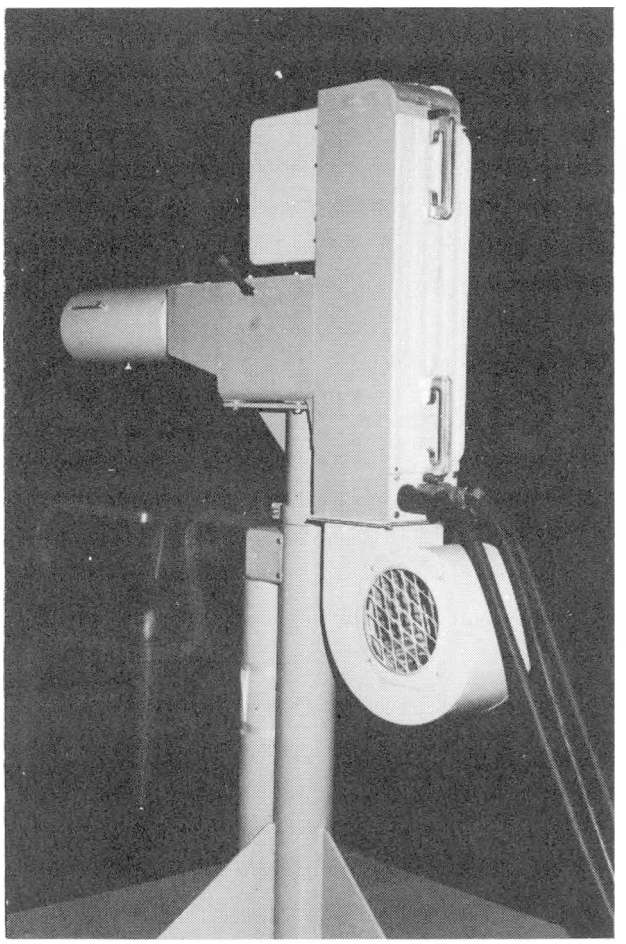


Fig. 1 – Solar Simulator

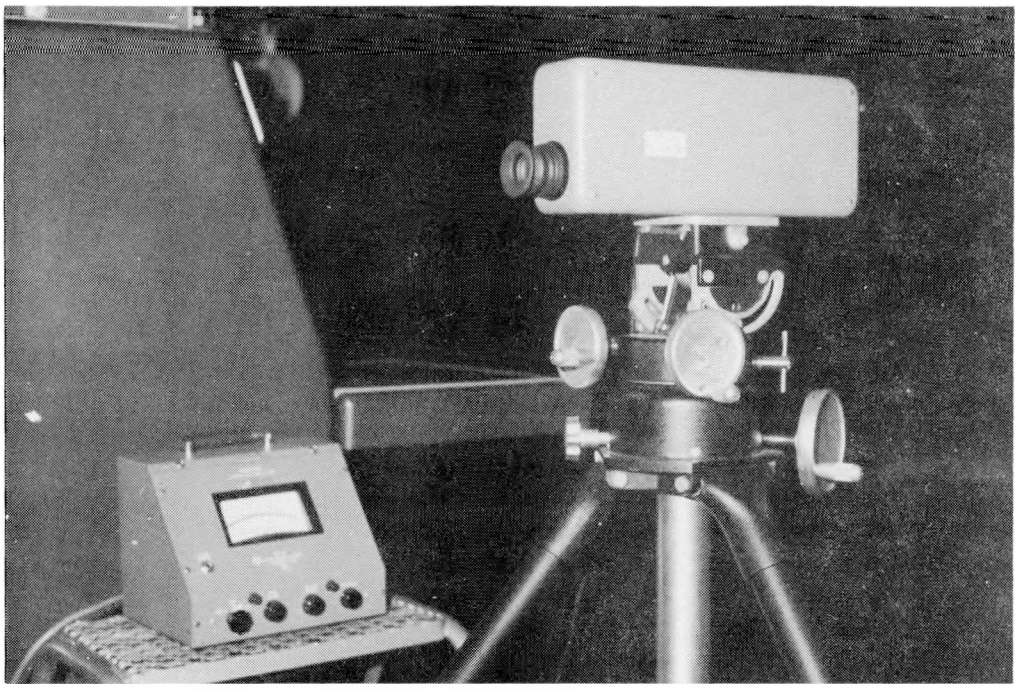


Fig. 2 – Photometer

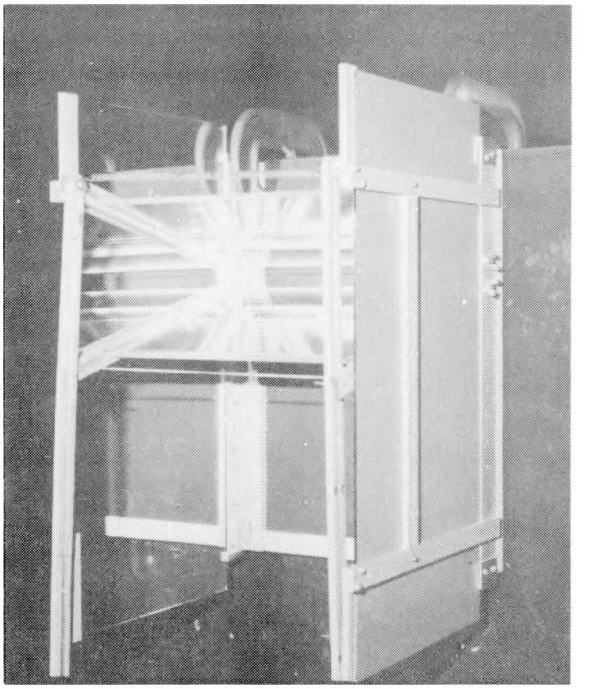


Fig. 3 – Adjustable Model for Experimental Measurements of Groove Concentration Ratio

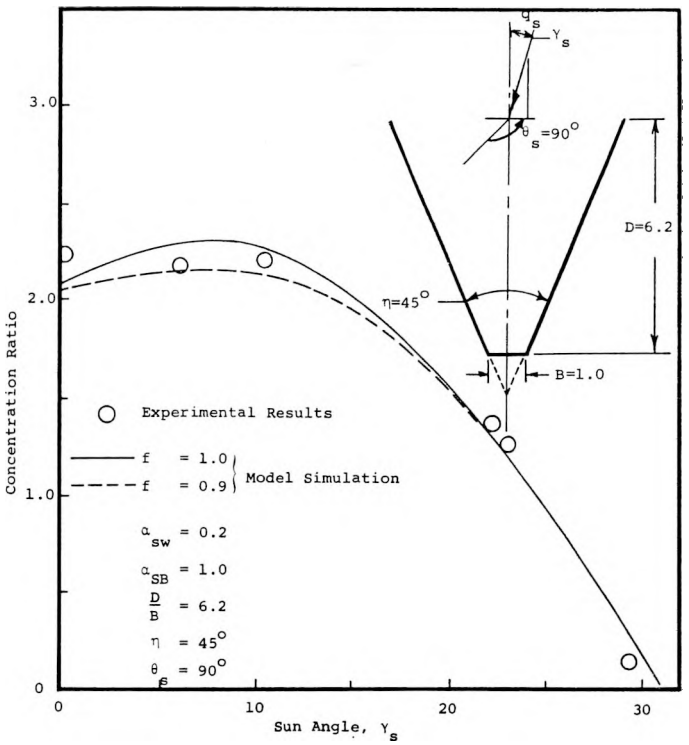


Fig. 4 – Comparison of Analysis and Experiment for Effect of Solar Angle on Concentration Ratio at Base of Mirrored-Wall Groove

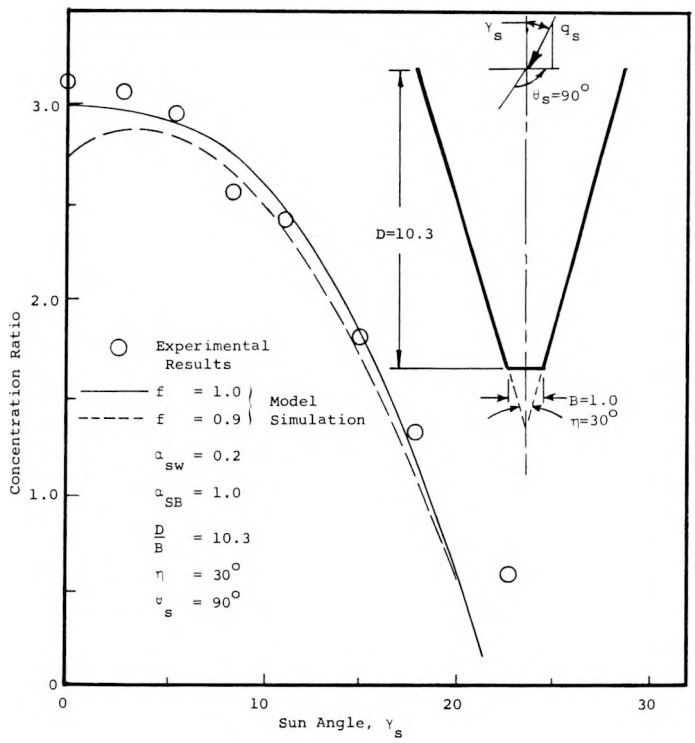


Fig. 5 – Comparison of Analysis and Experiment for Effect of Solar Angle on Concentration Ratio at Base of Mirrored-Wall Groove

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STUDIES ON METHODS FOR REDUCING HEAT LOSSES FROM FLAT-PLATE SOLAR COLLECTORS

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My colleagues at the University of Waterloo, T.E. Unny, G.D. Raithby and I are conducting a number of studies, all related to methods for reducing heat losses from flat-plate solar collectors. These include studies on (i) heat transfer by free convection across inclined air layers such as occur in flat-plate collectors, (ii) suppression of free convection in these layers by honeycombs; and (iii) the transmittance of a new type of inner cover. This work is supported by a grant from the National Science Foundation in the RANN Program.

Several of the studies centre around a general-purpose apparatus which we have built up for measuring free convective heat transfer in confined air spaces. Sketched in Figure 1, it is described fully in references [1-3]. It consists essentially of two parallel isothermal copper plates, each 56 cm by 61 cm by 1 cm. The upper plate is cooled and the lower is heated by two separate circulating water streams which pass though tubes soldered to the rear of the plates. The heat exchange between the two plates is determined in the central 13 cm by 13 cm region of the lower plate where a separately electrically heated plate is imbedded with its surface flush with that of the lower plate. The temperature difference between the two plates is measured by thermocouples imbedded into each plate. The plates are inserted into a pressure vessel in which the pressure can be varied from 10 Pa to 700 k Pa (10^{-4} to 7 atmosphere). The whole system, including the pressure vessel can be rotated so that the plates can make any angle with respect to horizontal.

The air gap between the two plates (which is adjustable from 0 to 12 cm) can be thought of as representative of the air gap between the absorber plate and the glass cover (or between two glass covers) in a conventional flat-plate collector. By placing a honeycomb between the two plates, the system is also representative of a honeycomb flat plate collector. Due to the principle of dynamic similarity, free convective heat transfer measurements made with varying pressure, but with fixed temperature difference and gap width are applicable to many combinations of temperature difference and gap width in an actual solar collector. The provision for varying the pressure therefore simplifies considerably the experimental procedure and make the apparatus quite flexible. It is particularly important in the measurements with honeycombs since it is possible to cover all honeycombs of a given cell aspect ratio by tests on one honeycomb, thereby eliminating the need to construct a large number of honeycombs. Figure (2) shows a photo of the appratus with a honeycomb in place.

We are in the process of measuring heat transfer across air layers both with and without honeycombs. In the case of layer without a honeycomb, our results for the horizontal layer are reported in [3]. We have just completed correlating a set of data for the tilted layer; our recommended equation for the Nusselt number is:

$$Nu = 1 + 1.44\left[1 - \frac{1708}{Ra\cos\theta}\right]^{\bullet}\left(1 - \frac{1708\,(\sin 1.8\theta)^{1.6}}{Ra\cos\theta}\right) + \left[\left(\frac{Ra\cos\theta}{5830}\right)^{1/3} - 1\right]^{\bullet}$$

where θ is the angle from the horizontal, and Nu and Ra are as defined in [2]. In this equation, square brackets like so: $[\ ]^{\bullet}$ indicate that if the argument inside the bracket is negative, the quantity is to be taken as zero, i.e:

$$[X]^{\bullet} = (|X| + X)/2$$

where X is any quantity. The details of arriving at this equation will be reported in [5]. The equation at present is recommended only for $0 \leqslant \theta < \sim 70°$ and $0 \leqslant Ra \leqslant 10^5$ although it is probably valid up to much higher Ra. In the case of an air layer with a honeycomb, our results for the horizontal layer are reported in [1]; those for the inclined layer are incomplete.

In addition to experimental studies on air layers, we are also carrying out analytical studies, again both with and without a honeycomb. The analytical study for the inclined honeycomb cell is mainly aimed at determining the heat transfer associated with the base flow at Rayleigh numbers below critical and establishing bounds for the critical Rayleigh number. The methodology consists of numerically modelling the fluid flow on a digital computer. In addition, we are using a new general (but approximate) method for analyzing free convection problems [5, 6] to analyze the inclined air layer of moderate aspect ratio and/or having $\theta > \sim 70°$.

We are also looking at a new type of inner cover for a flat plate solar collector,- the V-corrugated inner cover. Sketched in Figure 3, this cover is a thin plastic sheet folded into V-corrugations. It appears that under the right conditions this cover might have a higher transmittance to solar rays than the standard flat inner cover. This is because, as shown in the Figure, reflected rays from the top and bottom surface of the cover, are not reflected away from the absorbing surface, as is the case of the flat inner cover, but rather are reflected toward the absorbing surface, and hence should not be lost. To be sure that a higher transmittance is actually obtained, account must be taken of the multiple reflections in the V-corrugated cover, the absorption inside the plastic film, the dependence, and the spectral and polarization effects. However, we feel that this idea may be worth pursuing and are therefore investigating it by experimental and analytical studies.

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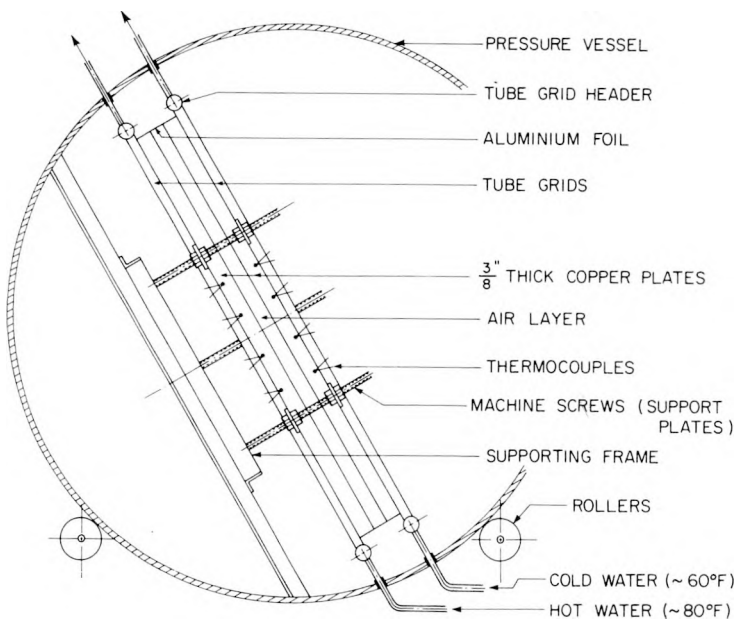


Fig. 1 – Sketch of the Experimental Apparatus

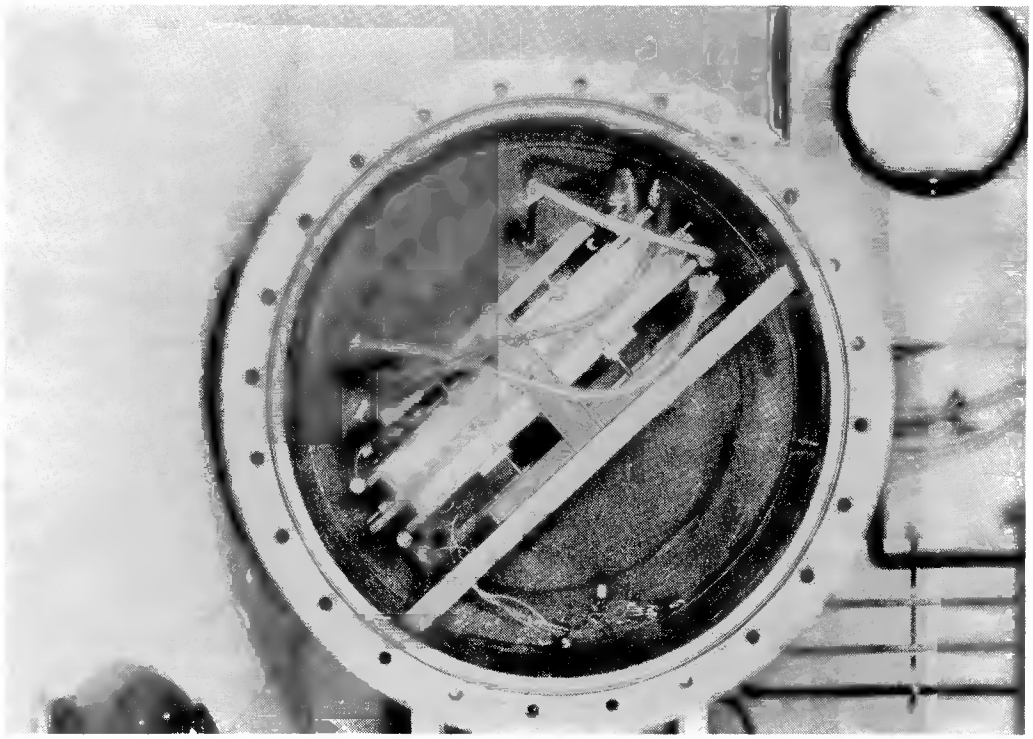


Fig. 2 — Photo of Experimental Apparatus with Honeycomb in Place

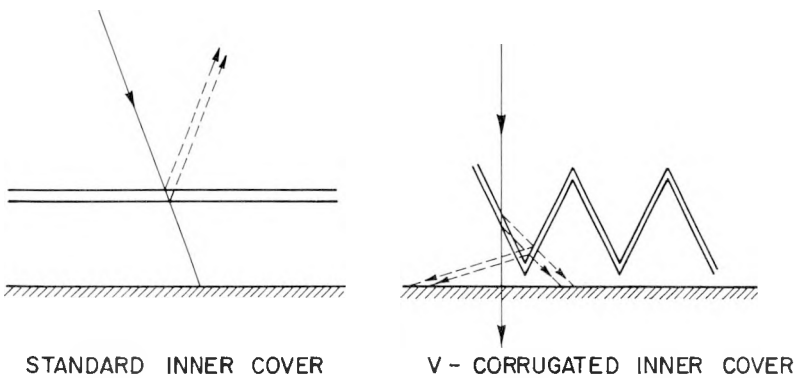


Fig. 3 — Sketch of a V-Corrugated Inner Cover Showing Solar Rays

DISCUSSION

Question (D. M. Deffenbaugh, Southwest Research Institute): Will you be studying the heat transfer characteristics with and without the honeycomb for reduced pressure?

Answer (K. G. T. Hollands, University of Waterloo): Yes.

Question (Erik A. Granholm, Bendix Aerospace Systems Division): Have you investigated the use of specular reflective surfaces applied to your honeycomb surfaces? Will this increase the efficiency of the flat-plate collector?

Answer: We have not investigated the use of specular reflective surfaces. It seems to us that the transparent honeycomb has greater potential for improved collector performance, since it should be possible to obtain much higher transmittance to solar radiation, particularly at high angles of incidence. However, to answer your second question, I would say that, under the right conditions, it would increase collector performance. I believe that Professors Buchberg and Edwards have demonstrated this at UCLA.

Question (Stanley A. Mumma, Ohio State University): How do you measure velocity profiles induced by natural convection between the plates?

Answer: We do not measure these profiles. To establish if there is convective flow (other than the creeping base flow), we measure the heat transfer as a function of pressure. When convective cells start, there is a dramatic rise in heat transfer with pressure.

Question (Carl G. A. Stousland, Rensselaer Polytechnic Institute): What do you see as the critical spacing between the honeycomb and the cover plate and honeycomb and the absorber?

Answer: Very little is known about the dependence on the spacing mentioned. In our measurements reported in [1], this spacing varied across the honeycomb from zero to about 0.2 mm, and results were approximately in line with theoretical expectations on the basis of the cells' being completely closed top and bottom. Certainly, too large a spacing would cause a reduction in the critical Rayleigh number, both due to the possibility of circulation between adjacent cells, and the effective "slip" boundary condition that would apply at the top and bottom bounding surface.

Comment (Kenneth N. Marshall, Lockheed, Palo Alto): Could I add something, since I debated the issue on that? During our program we will be examining those parameters and, hopefully, we will come up with experimental data to show what the optimum distance will be.

I would like to add one more comment here regarding Dr. Holland's remarks on honeycombs and selective coatings: a potential system that I see is a very good selective surface, with a Teflon honeycomb to suppress the convection as much as possible. Teflon has the advantages of high transmissivity and thermal stability. If you use a very thin and highly transparent–yet durable–cover material (getting away from glass), you can look forward to a very light-weight collector with high transmissivity to solar radiation, suppression of convection, and the selective coating to suppress radiation. I throw that out as food for thought. This is the direction in which we are trying to move.

Response (Redfield Allen, University of Maryland, Facilitator): Thank you.

TRANSPARENT GLASS HONEYCOMB

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Objectives and Background

A honeycomb structure placed between the absorber plate and the transparent cover plate of a flat plate collector is well-known to be highly efficient in reducing losses of energy, primarily in the suppression of convection.[1] This permits the absorber plate to attain high temperatures. In addition to the possibility of higher efficiencies per unit area of collector, the higher temperatures are particularly desirable for solar cooling purposes. The honeycomb can be non-transparent and reflective[1] or transparent.[2] The thin-walled transparent honeycomb structures based on the organic plastic Mylar have demonstrated significant improvement of efficiencies.[2] Because of the many undesirable characteristics of organic plastics such as deterioration in the UV, low glass-transition temperatures, absorption of water, etc., we proposed to evaluate transparent thin-walled honeycombs based on inorganic glasses. Preliminary estimates indicated that if mass production is possible, the cost of an inorganic glass honeycomb is not excessive.

The objectives of this one-year preliminary program are to design, build and test a few thin-walled inorganic glass honeycombs of various geometries. From the performance and consideration of costs, one system will be selected. An industrial company (Hanibal Scientific, Brunswick, Georgia) will develop the continuous manufacturing process for the thin-walled glass. The final goal at the end of the one year period is to construct a 2' x 2' test module, evaluate its performance and offer recommendations for future applications.

This program is a collaborative effort between UCLA (H. Buchberg, D.K. Edwards, J.D. Mackenzie) and Hanibal Scientific (R. Plumbo) with active consultation with the Glass Division of PPG Industries, Inc.

Plans

A variety of honeycomb structures will be evaluated. Figure 1 shows a proposed thin-walled structure based on glass tubings. Figure 2 shows a proposed thin walled structure based on corrugated sheets. These designs were proposed because they are amenable to continuous glass manufacturing techniques.

Accomplishments to Date

In the two months since the start of this project, we have accomplished the following:

1. Thin-walled (10 mil) rectangular glass honeycomb structures have been built and tested in a simple 6" x 6" unit. One such structure is shown in Figure 3. For a non-selective black absorber, such honeycombs are much more efficient than a double glazed flat plate collector.

2. Thin-walled (10 mil) glass tubings of 1/4" diameter have been manufactured by Hanibal Scientific with a continuous method.

3. Thin-walled honeycombs based on the 1/4" diameter tubings have been assembled and tested in a simple cell with a non-selective black absorber as for (1) above. The preliminary results are shown in Figure 4. Again, the honeycomb with one transparent cover plate is much more efficient than a double glazed structure without a honeycomb.

4. A technique has been developed to fusion-bond the thin-walled glass tubings together to form the honeycomb.

5. Theoretical studies of the performance of honeycombs under a variety of conditions have begun. Quantitative measurements to obtain efficiencies have been started. Data will be obtained for both selective and non-selective absorber surfaces.

Acknowledgments

This program is supported by NSF Grant No. AER 74-08848.

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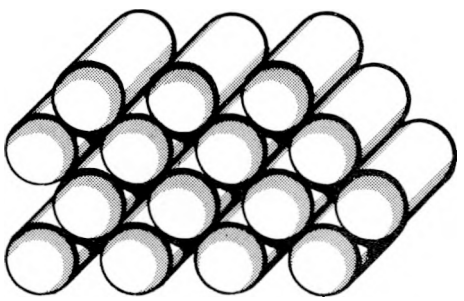


Fig. 1 — Proposed Honeycomb Structure Based on Thin-Walled Tubes

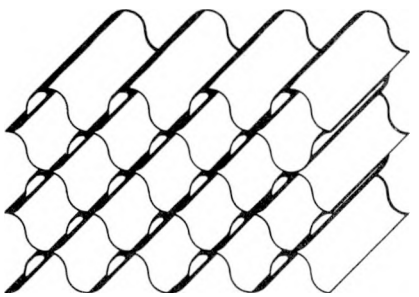


Fig. 2 — Proposed Honeycomb Structure Based on Corrugated Thin Glass Sheets

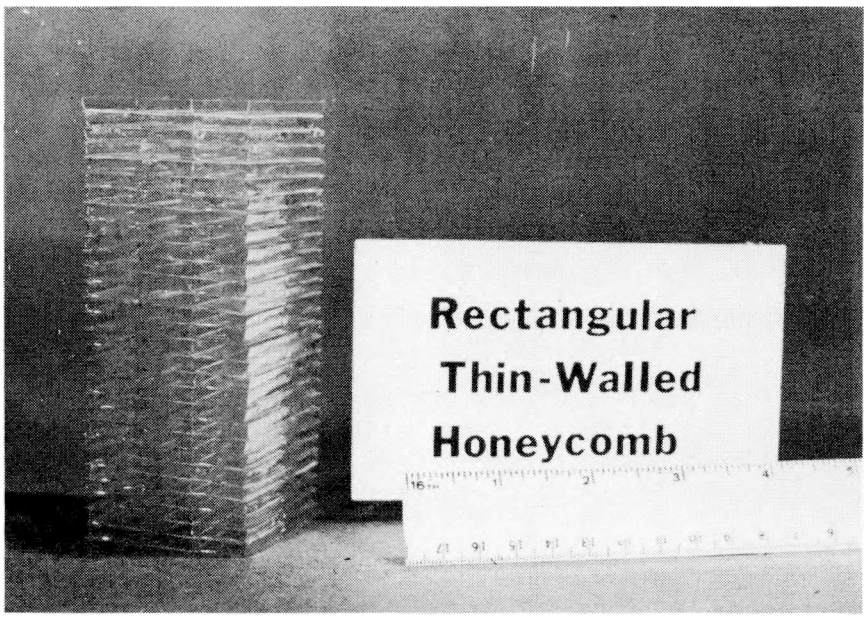


Fig. 3 — Rectangular Thin-Walled Honeycomb Made With 10-Mil Inorganic Glass Sheets

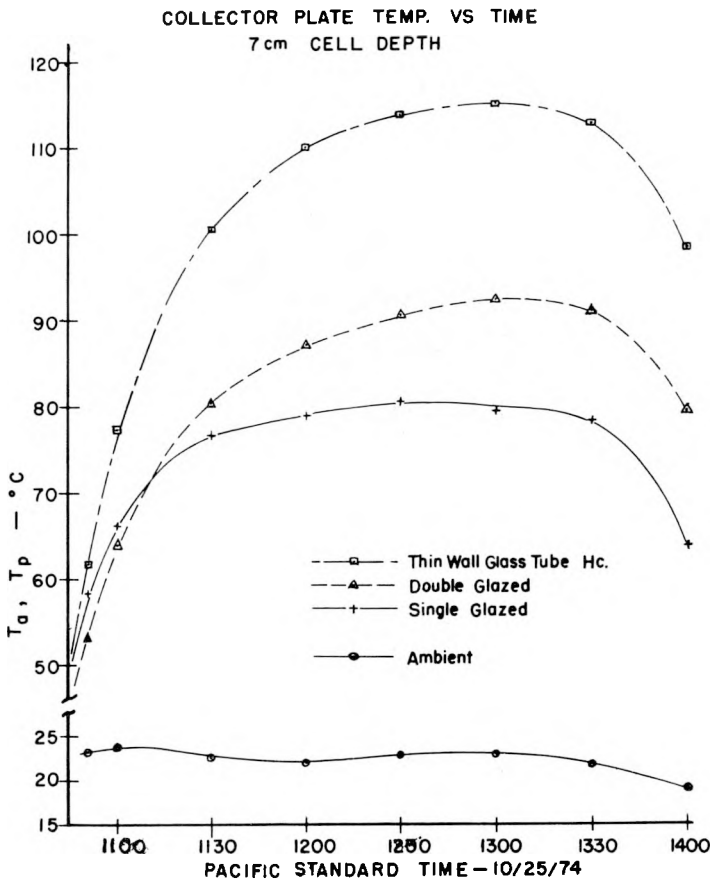


Fig. 4 — Preliminary Results for Simple Collectors Showing Collector Plate Temperatures (T_p) and Ambient Temperatures (T_a)

DISCUSSION

Question (Unidentified): Do you anticipate any problems with abrasion and, hence, glass weakening from glass-to-glass contact between the glass honeycomb and glass cover plate?

Answer (John D. Mackenzie, UCLA): No.

Question (Henry N. Chuang, University of Dayton): Who manufactures or provides those plastic or inorganic glass transparent honeycombs, and are they commercially available?

Answer: Thin glass honeycombs are not yet commercially available.

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DEVELOPMENT OF A FLAT-PLATE SOLAR COLLECTOR USING TRANSPARENT PLASTIC HONEYCOMB*

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ABSTRACT

A program to develop a honeycomb covered flat plate solar collector for use in the temperature range of 180 to 250°F (355 - 395°K) utilizing thin transparent plastic material for the honeycomb is described. The concept of using honeycomb to suppress the convection and radiation losses is reviewed, and the advantages of considering thin film plastic honeycombs are presented. The primary considerations in selection of materials and the final honeycomb configuration are discussed. Accomplishments during the first two months of the contract are presented.

INTRODUCTION

Utilization of solar energy for comfort conditioning of buildings requires the use of collectors having reasonable efficiency at temperatures in the vicinity of 220°F (378°K). This temperature is required for use of the collected energy in both heating and cooling of the building, thereby making maximum use of the total collector system throughout the year. Presently available solar collectors have relatively low efficiencies at these temperatures due to excessive convection and re-radiation losses; therefore, the development of collectors with improved performance at elevated temperatures is of prime importance for economic utilization of solar collector systems.

Honeycomb designs have been shown analytically to reduce convection and re-radiation losses.[1,2,3] Experimental studies have been performed on aluminum and paper thin-wall honeycomb[3,4] with some success; however, relatively poor performance occurred due to a sharp decrease in solar transmittance at solar incident angles off normal.[5] The potential advantages of honeycombs that are transparent to solar energy have been recognized by previous investigators,[1,2] and initial studies at LMSC[5] in 1973 with mylar honeycomb demonstrated the increased performance potential of this approach.

As a result of this latter work, the present program was conceived. The primary objective is to develop a high-performance collector design for use in the temperature range of 180°F (355°K) to 250°F (395°K) using thin transparent plastic honeycombs. Primary considerations in this work will be to select a material and a honeycomb design that lends itself to economical mass production for large scale implementation. The investigation will consider various combinations of honeycomb, absorber surfaces, and transparent cover materials to establish an optimum flat plate collector design. The period of performance for the program is September 12, 1974, through October 21, 1975.

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*Work performed by the Lockheed Palo Alto Research Laboratory, Palo Alto, California, for the National Science Foundation/Research Applied to National Needs under Contract NSF C-956.

Transparent Plastic Honeycomb Collector Concept

LMSC has pursued a solution through use of a thin transparent plastic honeycomb over the collector surface of either flat black or a selective coating, as shown in Fig. 1. This design was selected for evaluation following a comprehensive definition study because it provides the potential for achieving maximum daily solar collection and lowest cost with available materials and manufacturing techniques.

An initial experimental study at the Lockheed Palo Alto Research Laboratory[5] of three commercial honeycomb materials evaluated the solar transmittance and hemispherical emittance. Figure 2 shows the solar transmittance of several honeycomb and cover materials as a function of solar incidence angle;[5] Figure 3 shows the effective total hemispherical emittance of absorber, honeycomb, and cover combinations.[5] The 3 mil thick Mylar exhibits a relatively high transmittance compared to either aluminum foil or paper honeycomb and is preferred for a fixed, nonoriented collector. In addition the effective emittance of the collector system is substantially increased by the transparent honeycomb.

The results on a 0.0929 m^2 Mylar honeycomb test model with various combinations of cover materials on flat black and selective black absorber are shown in Fig. 4.[5] The aspect ratio used for this work was not optimum due to limitations in availability of materials; however, the results serve to illustrate the advantages of employing transparent honeycomb for flat plate solar collectors.

RESEARCH AND DEVELOPMENT PLAN

The approach of the present program is first to investigate various materials to determine their properties, producibility, and cost, second to predict collector performance for the most promising materials using an available computer program, and then to choose honeycomb T/D ratios and test various prototype designs. Finally, a full scale collector of the best system will be constructed and evaluated.

The solar transmittance, hemispherical emittance, and convective heat transfer of several T/D ratios will be measured to determine the most effective configuration. Test panels 43 cm x 127 cm in size with honeycombs made from promising candidate materials will be tested for optical property characteristics and mounted in collector assemblies to obtain relative collector efficiencies with both flat black and selective black coatings. The most promising honeycomb system will then be constructed in full-scale size (84 cm x 244 cm) for final proof-of-concept testing.

Prior to the design and manufacture of proof-of-concept, full-scale collectors, tradeoff studies of performance, manufacture, assembly, operation, maintenance, and cost will be performed. Also, as the test results are collected, the computer model will be updated so it will accurately predict honeycomb collector performance.

The research and development plan indicating the features of the analysis, prototype design, fabrication and testing, and full-scale design, fabrication and testing is shown in Fig. 5. Time phasing of the major tasks throughout the program is also shown.

ACCOMPLISHMENTS TO DATE

Analytical

A numerical model of a flat plate collector was developed under Lockheed Independent Development funding. This computer program, termed SOLAR has been used to calculate collector performance for a wide variety of designs involving various materials and configurations in support of the present NSF program. The computer model has the capability to separate and show the relative magnitudes of the heat losses from the collector due to the conduction, convection, and re-radiation components, as well as predicting temperatures for all collector components.

Application of the thermal computer model has been extended to study the effects of convection suppression on collector performance for a given set of input conditions. The predicted performance of a honeycomb collector as a function of effective collector emissivity is presented in Fig. 6. The collector consists of a Mylar honeycomb system with one Teflon cover. The case is for an average collector temperature of 200°F (366°K), incident solar angle of 30°, and an effective $(\tau_s \alpha_s)$ product of 0.86 at the absorber surface. The plotted results show the limits of expected collector efficiency as a function of the amount of convection suppression from the honeycomb design. The results indicate that with complete convection suppression and for low effective emissivity, the efficiency can approach 70% for this particular system.

Equations for predicting the effective radiation characteristics (i.e. α_s and ϵ) of transparent honeycomb collectors have been developed[6] in support of the solar collector work being done at the Lockheed Palo Alto Research Laboratory.

Materials and Honeycomb Configuration

Candidate honeycomb materials have been selected, which include Mylar, Tedlar, Lexan, Kapton, and Teflon. These candidates represent a range of optical properties, environmental stabilities, fabrication characteristics, and costs from which trade off comparisons can be made. Each material has unique advantages and disadvantages in terms of honeycomb collector usage. Under this project trade studies will be performed to determine the optimum system in terms of a given set of requirements. Optical and physical properties of these materials are in the process of being compiled.

A selection has been made for the honeycomb configurations to be tested during the initial screening tests. These include a hexagonal cell size of 0.48 cm and T/D ratios of 2, 5, and 10. Film thicknesses between 0.0025 cm and 0.0056 cm are being considered.

CONCLUSION

Economic utilization of solar collector systems for temperature control of buildings requires development of collectors with improved efficiency at high temperatures compatible with requirements of present refrigeration systems. Both analytical and experimental investigations to date have shown that transparent honeycomb flat-plate collectors provides the potential for achieving these higher efficiencies. However, much work remains to be done to experimentally determine the performance characteristics of thin-film transparent plastic honeycomb collectors and to establish an optimum system in terms of performance and cost criteria. The program has the objective of achieving this goal.

1. G. Francia, "A New Collector of Solar Energy - Theory and Experimental Verification - Calculation of the Efficiencies," Paper No. 594B, SAE, Oct. 1962.

2. K. G. T. Hollands, "Honeycomb Devices in Flat Plate Solar Collectors," Solar Energy, Vol. 9, 1965, p. 159.

3. H. Buchberg, O. H. Lalude, and D. K. Edwards, "Performance Characteristics of Rectangular Honeycomb Solar-Thermal Converters," Solar Energy, Vol. 13, 1971, pg. 193.

4. H. G. Lorsch, "The Use of Solar Energy for Residential Space Heating," Energy Conversion, 13, 1973, p. 1.

5. G. R. Cunnington and E. R. Streed, "Experimental Performance of a Honeycomb Covered Flat Plate Solar Collector," Proceedings of Inter-National Solar Energy Society, Oct. 1973, p. 47.

6. C. L. Tien and W. W. Yuen, "Radiation Characteristics of Honeycomb Solar Collectors," Submitted for publication in the International Journal of Heat and Mass Transfer, 1974.

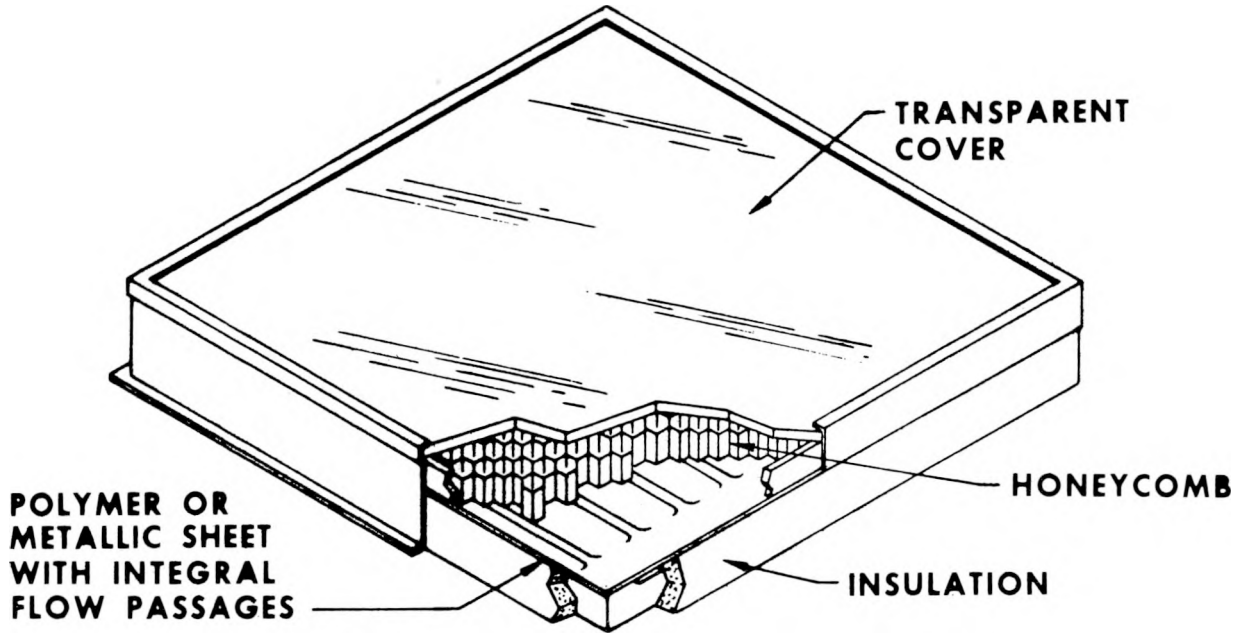


Fig. 1 – Honeycomb Covered Flat Plate Collector Design Concept

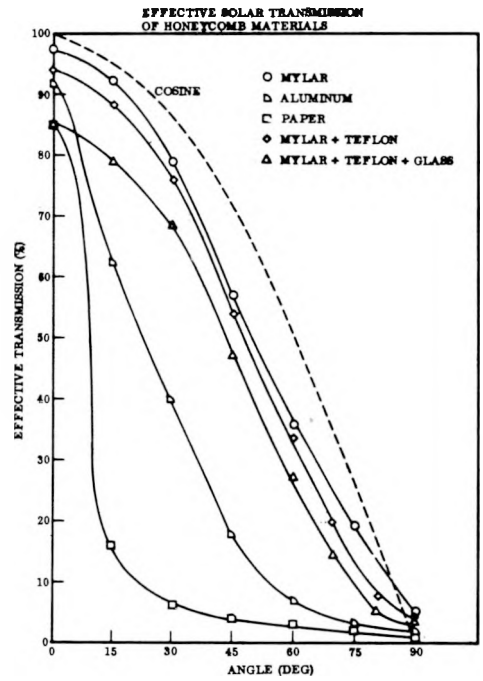


Fig. 2 -- Transmission of Various Honeycomb Designs

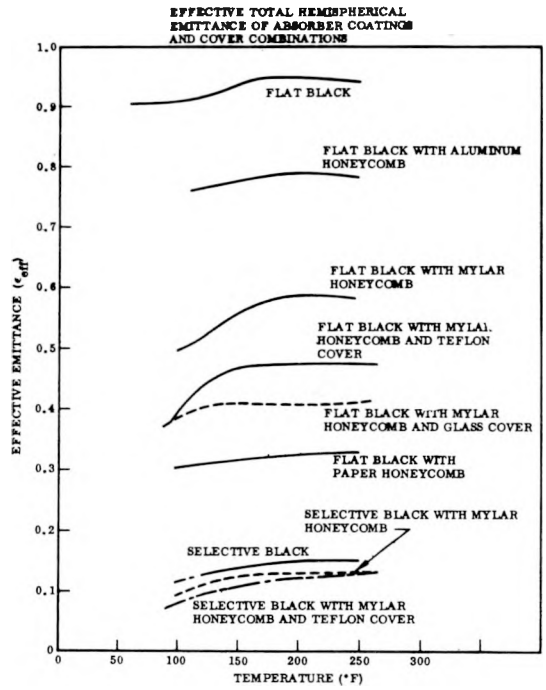


Fig. 3 – Effective Emittance as a Function of Temperature

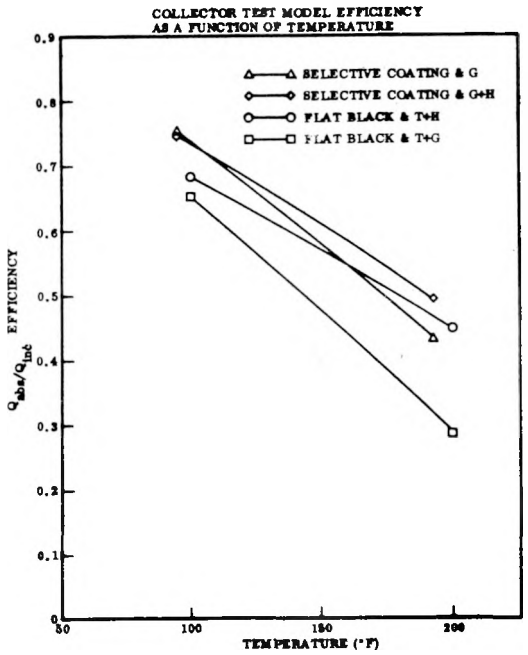


Fig. 4 — Collector Test Model Efficiency as a Function of Temperature

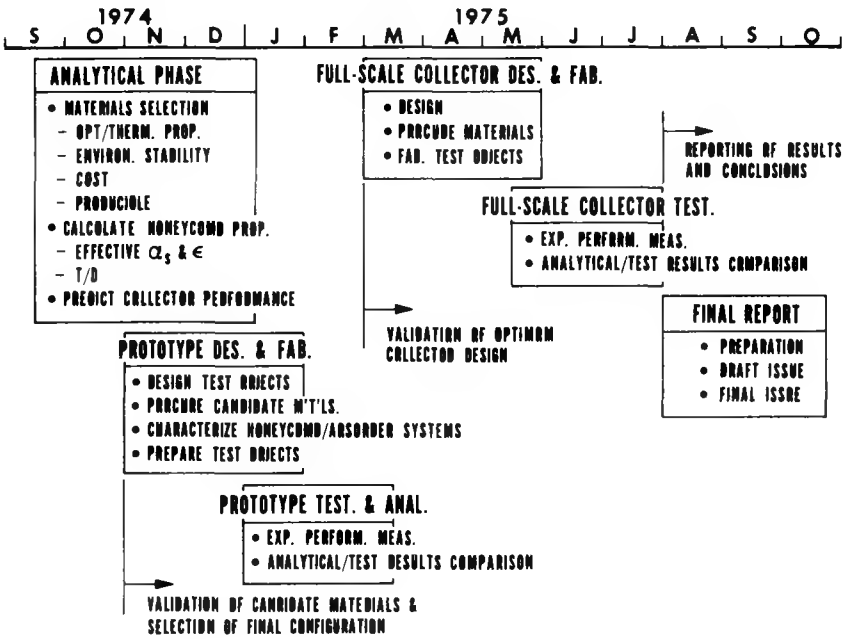


Fig. 5 — Research and Development Plan

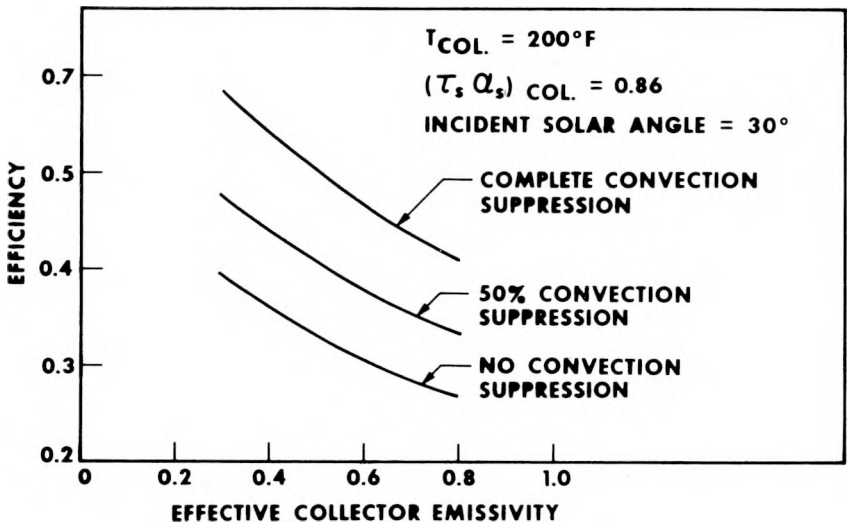


Fig. 6 — Predicted Performance of Honeycomb Collectors with One Teflon Cover

DISCUSSION

Question (Carl G. A. Stousland, Rensselaer Polytechnic Institute): What do you see as the critical spacing between the honeycomb and the cover plate, and the honeycomb and the absorber?

Answer (Kenneth N. Marshall, Lockheed): The honeycomb should occupy essentially all the space between the glazing and absorber plate. This provides full benefit from the honeycomb in reducing convective losses and also keeps the overall collector profile at a minimum. This applies only to honeycombs that have negligible thermal conductance, such as thin-film plastic honeycomb.

Question (Andrew E. Scoville, The Stanley Works): If the only purpose of the honeycomb is to suppress convective losses, then it would seem that the only significant material parameter—or characteristic—in selecting the honeycomb material would be thermal conductivity. Therefore, why are you planning on studying so many materials?

Answer: Thermal conductivity is not the only significant parameter in selection of a honeycomb material for collector use. Other parameters that must be considered are solar transmittance for both the plastic film and adhesive, infrared properties, temperature limits, environmental stability, cost, producibility, and material availability. Each of the materials selected for study under this contract has unique characteristics that are worthwhile considering for this application. As the program continues, a systematic analytical and experimental screening process will reduce the number of candidates to one or two for final evaluation.

Question (Unidentified): Temperatures of 200°-250° F are not practical design criteria for most solar collectors, since most collectors under no-load conditions will rise to 300°-400° F, especially with selective coatings. Where do you believe the plastic honeycomb can be utilized?

Answer: The temperature range of 200° to 250° F specified in my paper is the operational range for the honeycomb collectors to be developed under this contract. Obviously, in designing a collector for long-term operation, one must design for the maximum temperature to be experienced under such worst-case conditions as occur when the fluid stops flowing. Temperatures can exceed 400° F for collectors with selective coating under zero-flow conditions; therefore materials and design concepts to be employed should be selected to withstand this

temperature. It is recognized that most plastics will not survive this temperature; however some can, such as the Teflons and polyimides. The final design should, therefore, make use of these higher temperature plastics.

Question (Alvin O. Converse, Dartmouth College): What is the estimated cost and availability of the honeycomb structures?

Answer: The estimated cost of transparent plastic honeycomb depends primarily on the plastic material used. Price estimates range from 50 cents per ft^2 for Mylar, $1 per ft^2 for Tedlar, $1.30 per ft^2 for Lexan, to $4 per ft^2 for Kapton. At the present time, honeycomb of these materials is available only upon special order.

Question (George Szego, Inter-Technology Corporation): What precise benefit would be realized if the most suitable honeycomb were utilized? What is the approximate added cost? Is it worthwhile?

Answer: The benefits to be realized from a honeycomb-covered collector are greatly increased efficiency at temperatures above 180° F and a potential decrease in overall collector cost. A properly designed transparent honeycomb system will provide significant increases in efficiency using only one transparent glazing, as compared to the efficiency of the best double-glazed system. The cost of Mylar honeycomb, for example, is projected by honeycomb manufacturers to be 50 cents per ft^2 in production quantities. Since only one cover glass is required, this represents a potential savings of 50 to 80 cents per ft^2. Admittedly, higher temperature plastics are more expensive than Mylar; however, in terms of overall cost per unit of collected energy, a savings can be realized. Yes, it is worthwhile.

SOLAR ENERGY COOLING WITH ZEOLITES*

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Most solar energy refrigeration systems are based on the absorption refrigeration cycle which uses the change with temperature of the solubility of a gas in a liquid. Since this process is thermally activated, its dependence on temperature is exponential. The development of molecular sieve zeolites during the past ten years has provided solid materials capable of adsorbing large quantities of different gases and having a temperature dependence even stronger than exponential. The amount of gas adsorbed in a molecular sieve zeolite can be represented[1] by the equation:

$$a = a_o \theta_{n=2} + a_n \theta_n$$

where a_o is the limiting adsorption value of the gas at low temperature and

$$\theta_n = \exp -[RT \ln (p_s/p)/E_n]^n$$

with n being an integer between 2 and 5. Here R is the gas constant; p_s is the saturation pressure at temperature T; p is the actual pressure; and E_n is the activation energy, which is on the order of a few kilocalories per mole. Therefore, the dependence of gas adsorption on temperature is at least exponential with the square of temperature and may go as high as exponential to the fifth power of temperature.

The adsorption isotherms for water on Zeolite 4A are shown in Fig. 1 and those for water on silica gel are shown in Fig. 2. From Fig. 1, at 77°F zeolite temperature and 5mm Hg partial pressure of water about 24 lb of water will be adsorbed per 100 lb activated zeolite. When the zeolite is heated to 300°F, it will desorb water until, at 25mm Hg partial pressure, it reaches equilibrium with only 11 lb of water left per 100 lb of zeolite. Thus, if the zeolite is cycled between 77° at 5mm Hg and 300°F at 25mm Hg it will adsorb and desorb 13 lb of water per 100 lb of zeolite, which is equivalent to a compressor with a compression ratio of 5:1.

If the water vapor at 25mm Hg is condensed to liquid by cooling it in a condenser to below 80°F, and the liquid is evaporated in a coil at about 32°F to vapor at 5mm Hg, the cycle can reject heat from the condenser and pick up heat from the evaporator coil like any conventional refrigeration system.

*This work was sponsored by NSF/RANN.

The heat of vaporization of water at 35 °F is 1073 BTU/lb and the heat of fusion of ice is 138 BTU/lb; the evaporation of 13 lb of water, therefore, corresponds to 14,000 BTU or the equivalent of 100 lb of ice. Therefore, 100 lb of zeolite cycled between 77 ° and 300 °F will produce 100 lb of ice. If we use the solar day-night heating cycle for this process, it will take 1 ton of zeolite to produce 1 ton of air-conditioning. The present price of zeolite is about $700 per ton.

From Fig. 2, silica gel can adsorb and desorb about 10 lb water/100 lb adsorbent between the same temperature and pressure limits.

We have collected some preliminary data on the adsorption of Freon 11, Freon 113, and refrigerant R30 (Dichloromethane). While the differential adsorption-desorption of Freon is larger in weight (up to 40 lb Freon/100 lb zeolite), the heat of vaporization of Freon is only 70 BTU/lb so that the total cooling effect per 100 lb of zeolite will be only 20 lb of ice. Adsorption curves for Freon 12 and 22 will be measured shortly, and their cooling efficiency with zeolites will be determined.

One approach to utilizing zeolite for constructing a home air-conditioning system is as follows: The roof of the house is covered with zeolite panels in gas-tight containers. The panels are all connected to a gas-line manifold which leads down from the roof to a water-or air-cooled condenser, on the outside of the house, which is kept at or below 80 °F. The output of the condenser is fed into the house to an evaporator coil and from there to a storage tank in the basement. The whole system is gas-tight (like any air-conditioning system) and before use it is evacuated and charged with the working gas up to a partial pressure corresponding to the boiling point of the gas at or below 32 °F.

During the day, solar radiation heats the zeolite panels to about 300 °F, causing the zeolite to desorb the gas. When the pressure in the system reaches the saturation pressure of the gas at 80 °F, the gas will begin to be liquefied in the condenser. When cooling is needed the liquefied gas will be fed through a capillary tube to the evaporation coil, where it will evaporate at low pressure. The resulting vapor will be stored in the storage tank. The hotter the day, the larger the amount of desorbed gas, which automatically satisfies the larger cooling needs. At night, when the zeolite panels cool down, the partial pressure of the gas in them drops very low due to adsorption, and the system begins recharging by transferring gas from the storage tank, through a one-way valve, back to the panels on the roof. The adsorption of this gas generates heat in the panels which is rejected to the night environment. By morning, the panels are recharged and ready for another cycle of air-conditioning.

For example, if water vapor is used as the working gas, the system is charged when cold to a partial pressure of 5mm Hg (boiling point of 35 °F). During the day, the water vapor desorbs, and when the partial pressure reaches

25mm Hg (boiling point of 80 °F) the water vapor begins to liquefy in the condenser. When cooling is needed the condensed water is fed through a capillary tube to the evaporator coil where the partial pressure is kept below 5mm Hg. That causes the water in the coil to boil off at 35 °F and to produce the desired cooling effect. The water vapor is then stored in the storage tank at pressures below 5mm Hg until night. When the water vapor pressure in the zeolite panels falls below 5mm Hg the one-way valve opens and the panels get recharged.

In this approach the vapor pressure in the storage tank must always remain below 5mm Hg, even after a hot day when all the available water vapor from the zeolite panels has been desorbed. Therefore, if the tank were just an empty evacuated container, its required volume would be enormous. To reduce it to a practical size, it should be filled with an adsorbing material like silica gel, activated alumina or carbon. During the day this material will adsorb the vapor, keeping its pressure in the evaporation coil low. At night, since the affinity of zeolites for the gas is much larger than that of the sorbant in the tank, the zeolite panels will remove the gas from this sorbant and thus recharge the system for another cycle.

The zeolite air-conditioning system could be described as a large compressor, with compression ratio of 5:1 to 10:1 and one compression cycle per day. The rest of the refrigeration system is conventional. The time of adsorption and desorption depends on the amount of heat flow and gas flow. It is on the order of a few hours when heat and gas flow are not restricted. For this reason the roof panels are constructed of containers with a honeycomb core filled with zeolite powder as shown in Fig. 3. The honeycomb is made of aluminum and conducts the heat from the container surface through the powder. The gas diffuses through channels which are cut in the honeycomb to the tube on the right of the container and from there to the manifold.

The objective of this program is to construct a demonstration module (3'x3') consisting of 9 one-square-foot panels, which will contain a few hundred pounds of zeolite. The estimated cost of the panels is a few dollars per square foot, the cost of zeolite being less than $1/sq. foot. Therefore, the cost per ton of air-conditioning for full size systems is expected to be on the order of few thousand dollars, with no maintenance or energy cost thereafter.

No major problems have been encountered to date.

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1 M. M. Dubinin and V. A. Astakhov, Advances in Chemistry 102 (American Chemical Scoiety, Pub., Washington, D. C., 1971) part II, p. 70.

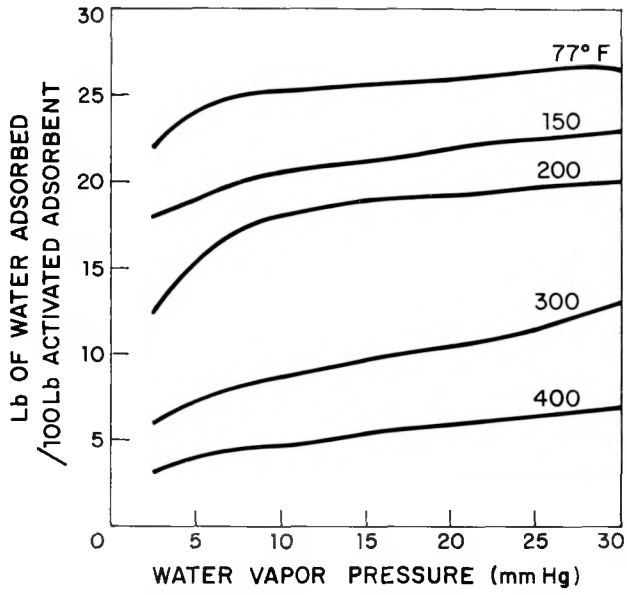


Fig. 1 — Adsorption Isotherms of Water on Zeolite 4A

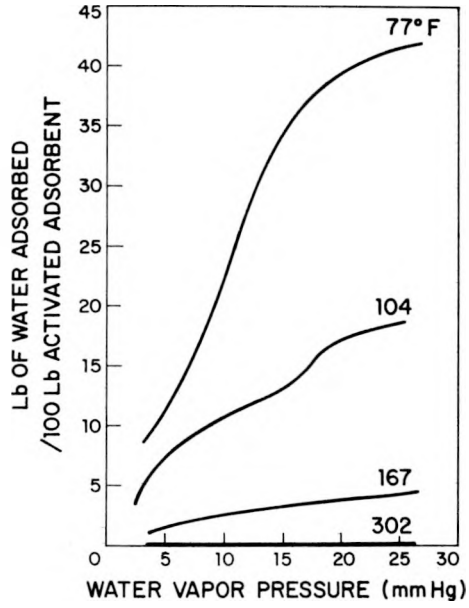


Fig. 2 — Adsorption Isotherms of Water on Silica Gel

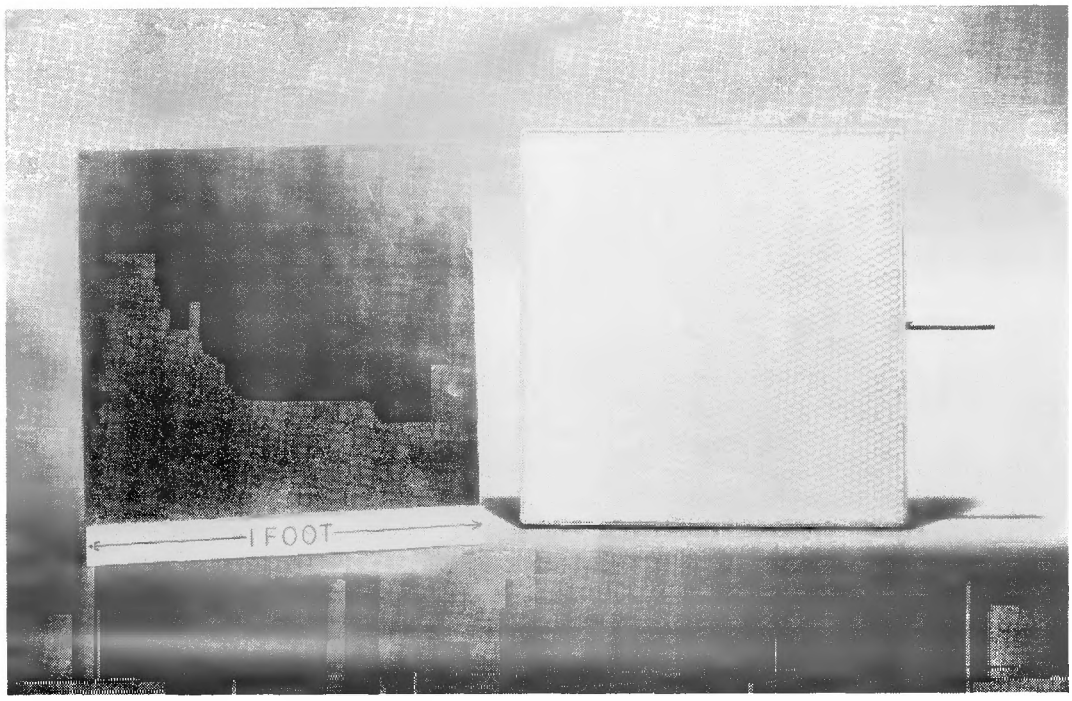


Fig. 3 – Front View of Zeolite Collector Panel with Aluminum Honeycomb just Prior to Final Assembly

DISCUSSION

Question (paraphrased from several): Please elaborate on the operation of the zeolite cooling system, and is dehumidification provided?

Answer (Dimiter I. Tchernev, MIT Lincoln Laboratory): The operation of the system is described in more detail in the written text of the presentation. The system acts as a one-cycle-per-day compressor with 10:1 compression ratio. The rest of the cooling cycle is conventional, i.e., condenser, heat exchanger, evaporator coil, etc. The system cools and dehumidifies like any conventional refrigeration system. It can be used for heating by reversing the roles of the condenser and evaporator as in any heat-pump system.

Question (Guy Ervin, Atomics International): Can zeolite be used as a thermal storage material? Do you have figures on the volume of zeolite needed per Btu recovered?

Answer: Zeolites can be utilized as heat-storage materials. Since the maximum water loading is 30 percent by weight and the heat desorption of water is about 1,800 Btu/lb of water, the maximum stored heat will be 600 Btu/lb of zeolite plus some contribution from the specific heat of the zeolite (which is small). Therefore, the theoretical heat storage capacity of zeolites is about 10^6 Btu/ton. At density of about 1.2, one ton of zeolite has a volume of about 200 gal.

Question (Anonymous): How long will it take to accomplish adsorption and desorption, assuming you achieve 300° F?

Answer: The times of adsorption and desorption are controlled by the heat flow in and out of the zeolite and by the presence of foreign gases (such as air). In a sealed and evacuated system, with the zeolite panels kept at constant temperature, the sorption and desorption times are on the order of a few hours.

52106

THERMIC DIODE SOLAR PANELS

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I Objective: The objective of NSF Grant GI-43897 is to develop low cost walls and roofs which change their conductivity depending on season and weather. A modular unit suitable for either wall or roof use is called a thermic diode solar panel. During the winter the panels absorb solar energy when the sun shines, while insulating at night. Conversely during the summer the panels insulate from the sun while dissipating to the night sky (Figure 1). The program's duration is one year.

II Description of Research: Each panel is constructed from a wood or fiberglass frame with sheet metal inner and outer surfaces, forming a box approximately four feet by eight feet by six inches thick (Figure 2). A three inch thick slab of insulation divides the box into two layers : a quarter inch thick sensor layer on the outer surface and a three inch thick storage layer next to the inner surface. The sensor and storage layers are water filled vinyl bags. The bags have openings such that the only convective flow from one layer to the other is through a control box and a return duct.

The control box is a cavity with short lengths of tubing connected to each layer. A small quantity of oil floats on the water inside the control box (Figure 3). When the outer surface of the panel is heated by the sun, the oil is not high enough in the control box to stop the convection of heated water from the sensor layer to the storage layer (Figure 4). Thus the sun heats the storage layer by convection. When the sensor layer becomes cooler than the storage layer, the oil water interface in the control box tube moves such that a column of low density oil just balances the pressure difference due to buoyancy of the two layers. Hence no convective flow occurs when the sensor layer is cooler than the storage layer. The net effect of the control box is to allow a preferential heat transfer direction: heat is easily transferred from outside to inside but little heat leaks back outside.

A summer diode is also contained in the control box; the vertical riser tube is now connected to the storage layer rather than the sensor layer (Figure 5). The summer diode (Figure 6), insulates from the summer sun when the outer sensor layer is hotter than the storage layer. On a summer night when the sensor layer is cooler than the storage layer, heat is dissipated out to the night sky. A simple three-way valve changes the control box from winter to summer operation; the valve must be moved twice a year.

III Program: The program to develop a thermic diode solar panel is divided into three parts;

1) Economic Evaluation: A computer program is being developed that evaluates the cost effectiveness of thermic diodes compared to gas, oil, and electric heating/cooling. The panels will be optimized for a variety of parameters: e.g. collector area, need for glazing, orientation, and location. Preliminary estimates suggest that the panels will cost little more than the walls and roofs which they replace. The program has been written and is awaiting solar data for final debugging.

2) Small Scale Panels: Small size panels are to be tested in an environmental chamber simulating solar heat, wind velocity, and outside temperature. Drawings for the environmental chamber are complete, procurement has been initiated. Interim testing on two small panels has verified: a) a twenty minute time constant, b) six months continuous operation, c) a diode resistance ratio of 200 to 1.

3) Full Scale Panels: Two full-scale panels are to be constructed and tested. Initiation of this phase awaits results from small scale testing.

IV Expected Problems:

1) Freezing: In most locations freezing of the sensor layer is probable; a calcium chloride solution is thought to prevent freezing without degrading the seals in the vinyl bags.

2) Over-Temperature: The vinyl bags can stand little internal pressure, so the vaporization of sensor liquid must be prevented. Elimination of glazing accomplishes this purpose but considerably reduces collector efficiency. The tradeoff will be determined by economic considerations. An alternative construction using a pressurized convection loop is being investigated to eliminate the overtemperature problem on glazed panels.

3) Sealing: Proven methods of sealing are to be used: induction heat sealing of vinyl.

4) Heat Extraction: Heat extraction from the storage layer will either be by direct radiation into the building interior or by convection through integral closed metal ducts attached to the storage layer. Forced circulation through these ducts allows interior temperature control, minimizes the fire hazard, and reduces condensation problems.

V Ongoing Studies: The not-so-obvious advantages of thermic diode panels are being analyzed to determine their impact. These include:

1) Aesthetics: A thermic diode house can be made to look identical to a conventional house. Panels can be angled,

colored, unglazed and even decorative.

2) Elimination of Glazing: Sufficient heat can be obtained from a large area of low efficiency collectors as easily as a small area of high efficiency collectors. If the collectors are inexpensive enough, high efficiency glazed collectors may not be needed.

3) Fail-safe: Thermic diode panels become insulators if they loose any liquid.

4) Low-Grade Heat Use: Being surrounded by the storage medium is an advantage because the solar heat input is useful even if the temperature drops below 70°F (less heat must be provided by auxiliary heating).

5) Modulator Construction: Thermic diode panels are expected to have a low manufacturing cost consistent with assembly line techniques. They can be transported empty and filled on site.

6) System redundancy: The possibility of a complete system failure is reduced enormously with many independent panels.

7) Low Maintenance : The absence of moving parts suggests that maintenance costs are low.

8) Self-Powered: The panels do not rely on an electric supply.

9) Simplified Installation : Since the panels are independent, there is no need for interconnections.

10) Shadow Performance: Many independent panels can absorb more heat than a single collector when a shadow moves across the collecting surface.

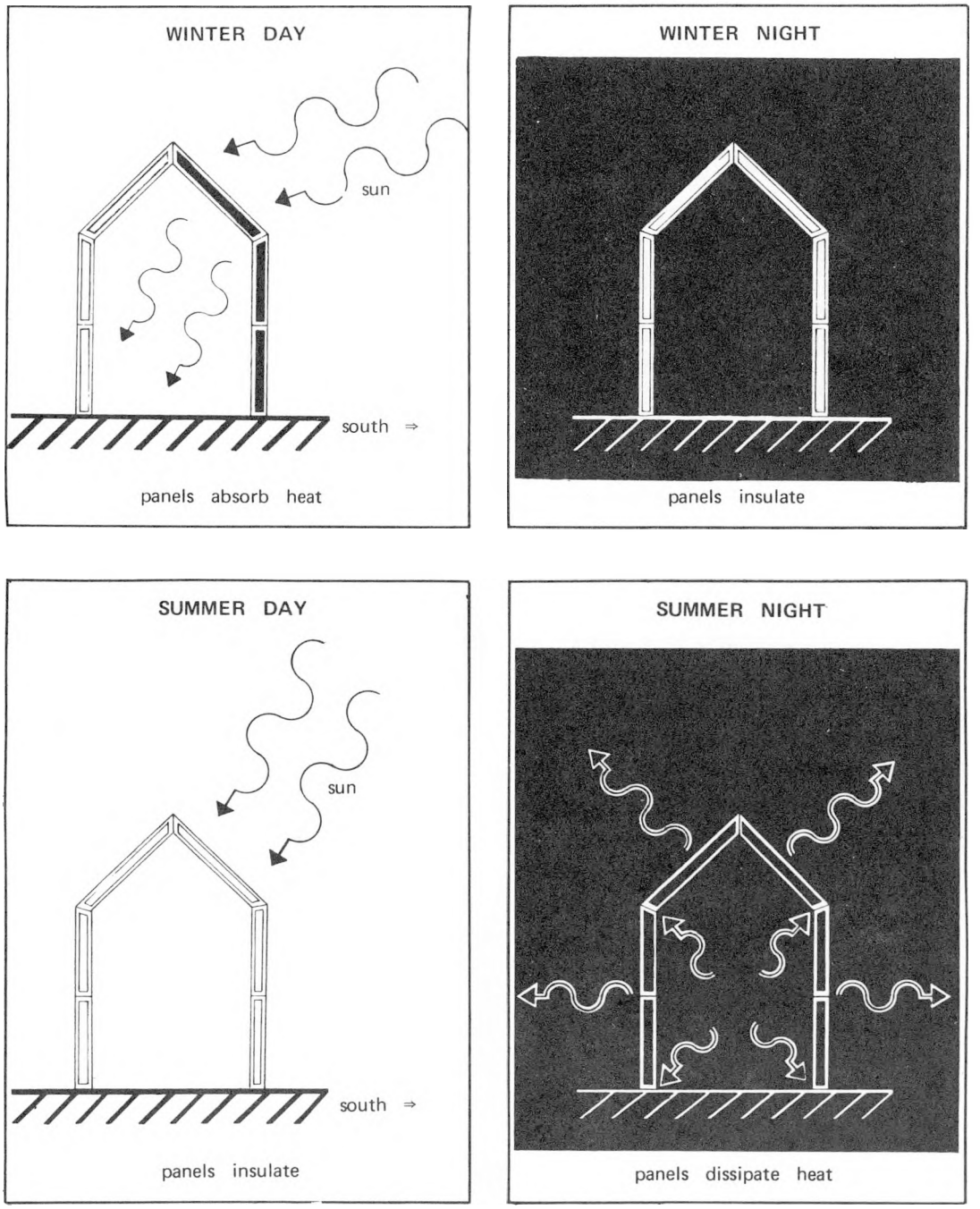


Fig. 1 – Residential Application

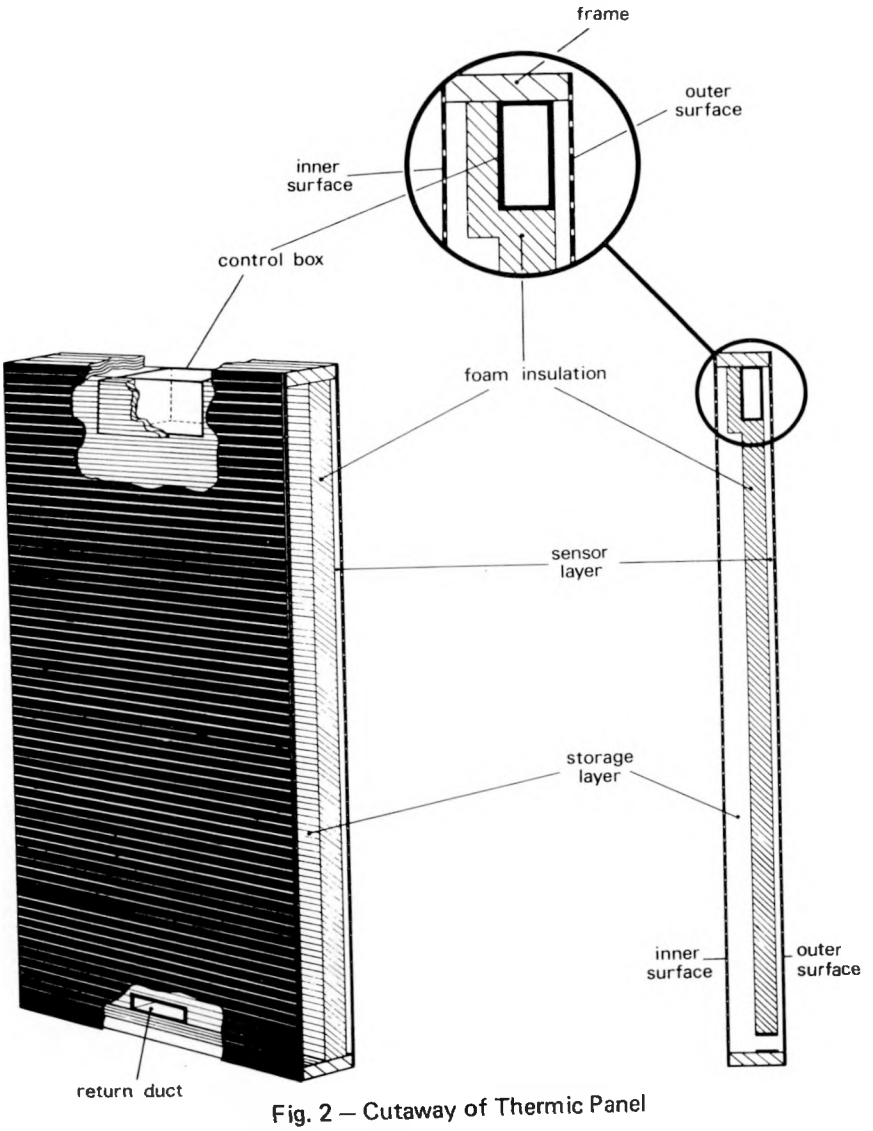


Fig. 2 – Cutaway of Thermic Panel

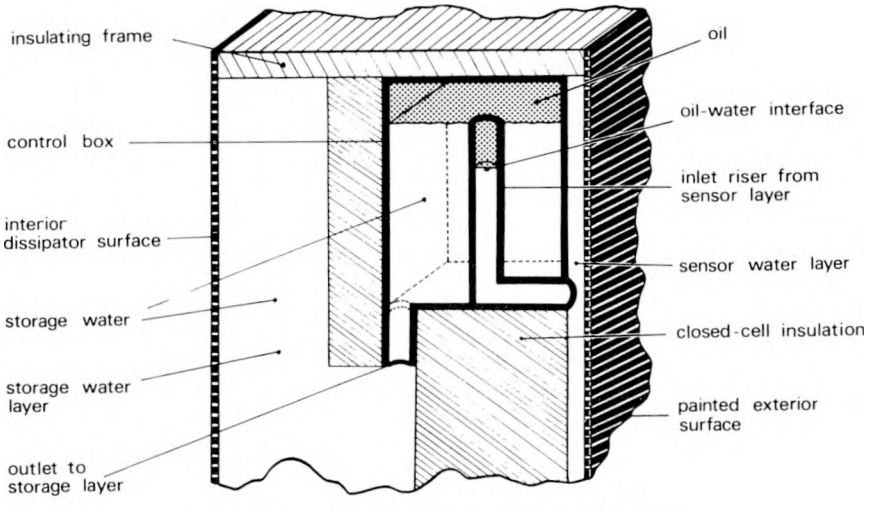


Fig. 3 – Cross Section of Winter Diode

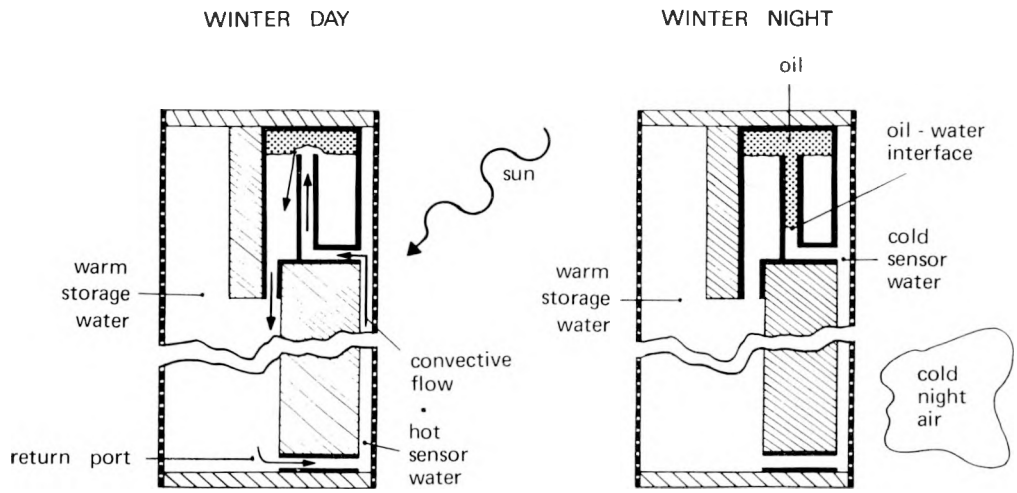


Fig. 4 – Operation of Winter Diode

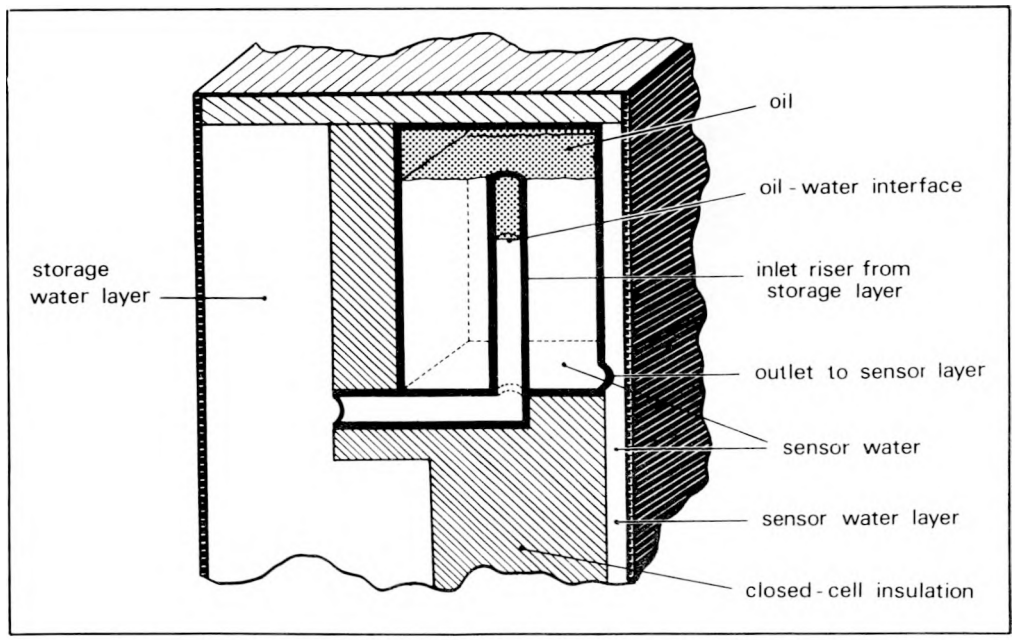


Fig. 5 – Cross Section of Summer Diode

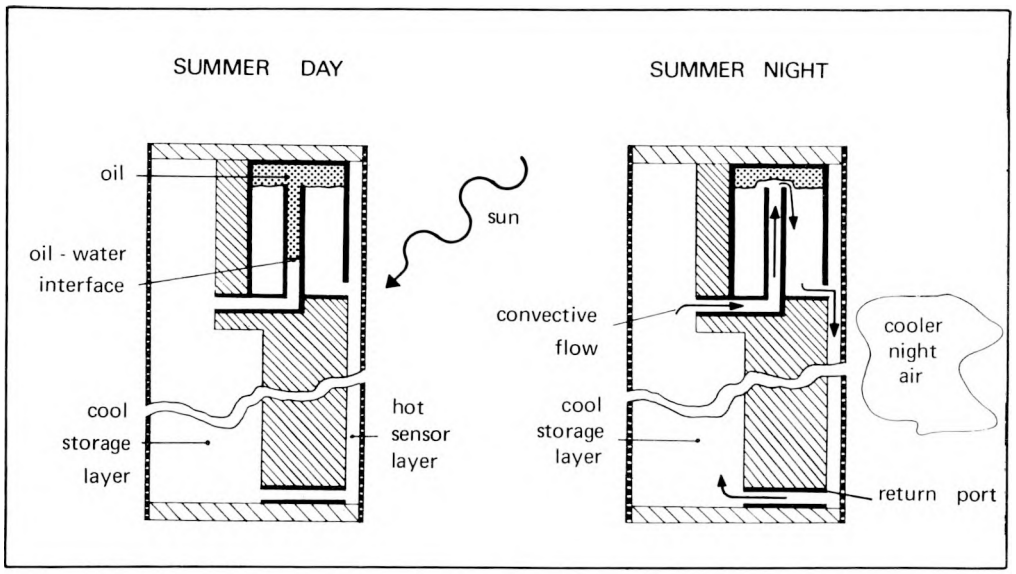


Fig. 6 – Operation of Summer Diode

DISCUSSION

Comment (Henry M. Curran, Hittman Associates, Inc.): Please comment on practical considerations–installation by construction personnel, possibility of leaks, people driving nails into panels, etc. Similar ideas have been found impractical in the past because of such considerations.

Reply (Shawn B. Buckley, Massachusetts Institute of Technology): Many of the practical considerations that you suggest have been considered. The independent, modular form of the panels should allow for easy installation by contractors (as well as replacement if damaged). Although the panels are quite heavy filled, they are designed to be transported empty and filled on site. Regarding leaks, the liquid is to be contained in vinyl bags protected by sheet metal inner and outer covers. Furthermore, they are fail-safe such that if leaks occur, the panels become ordinary insulators. Ducts are provided for draining away both condensed water and possible leakage. Forty-thousandths-inch-thick galvanized sheet steel should provide adequate protection to the outsides of the panel. The interior of the panel (also 0.040 inch thick) is separated from the interior wall by several inches of convection ducts and utility space, hopefully reducing nail punctures.

Question (Howard S. Katz, Sunearth, Inc.): How do you contend with house building codes that call for a wall to act as a shear panel (i.e., plywood sheathing, diagonal bracing)?

Answer: The panel is to be constructed of galvanized sheet steel 0.040 inch thick. Our calculations show that even a single thickness provides the same capability as a half inch of plywood sheathing in terms of both strength and rigidity. Whether house building codes will allow this substitution is another question.

Question (Douglas R. S. Hart, Lothlorien Farm): How do you interchange the summer and winter diodes?

Answer: Both summer and winter diodes are contained in each panel. A manual valve switches from winter to summer operation or back twice a year.

Question (Jerry J. DeSantis, Rensselaer Polytechnic Institute): Do you intend to construct an entire building of diode panels? Is there a connection between panels to maintain insulation values under thermal and structural movement?

Answer: Yes, we propose sheathing an entire building with diode panels. The exact mode of attaching the panels to a steel or wooden framework has not been finalized. However, we foresee panels attached side by side with slight gaps between panels. Caulking between the panels allows for thermal and structural movement while maintaining thermal insulation between panels. Otherwise, each panel acts independently.

SESSION 6

NUMERICAL MODELS

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COLLECTOR MODELING

J. W. Ramsey and R. N. Schmidt
Honeywell Inc.
Minneapolis, Minnesota

Presentation Summary

This presentation briefly describes two computer models which Honeywell has used extensively in the conduct of its solar energy studies. One model uses a numberical ray trace technique to analyze concentrating collectors. The other uses a nodal analysis to predict flat plate collector performances.

Concentrating Collectors -- A Monte Carlo digital simulation has been written for analyzing concentrating solar collection systems. The program can be used for a number of concentrating collectors including trough, dish and central receiver configurations. The method of analysis will be described by outlining the procedure as it applies to a parabolic trough solar collector. The procedure is shown schematically in Figures 1 and 2.

An incoming solar ray is defined and traced as it reflects at the concentrator surface, passes through (or reflects from) the glass envelope, and terminates by either striking or missing the absorber tube. The effects of mechanical imperfections in the system and of the optical properties of the materials encountered by the ray are included throughout the trace. Among the factors considered in defining a particular collector and its operation are: (a) the quality of the concentrator contour, i.e., RMS slope error; (b) the tracking accuracy; (c) the concentrator reflectance; (d) the envelope transmittance; (e) the absorber tube absorptance; and (f) the absorber tube alignment. The wavelength dependence of the collection process is handled by first carrying out the ray trace for ten wavelengths covering the solar range and then the results for each wavelength are weighted in accordance with the solar distribution and integrated.

Parametric investigations, using the model are reported in References 1 and 2. Described are the effects of: (a) the orientation of the collector tracking axis; (b) the spacing of collectors; (c) the concentration ratios; and (d) the rim angle of the concentrator. Typical results for a parabolic trough collector are shown in Figures 3 and 4. Figure 3 presents the predicted daily variation of absorbed power for a collector oriented east-west. Figure 4 depicts the yearly performance for collectors oriented both east-west and equatorially.

The collector for which the results of Figures 3 and 4 were generated had the following characteristics: (a) an aperture 12 meters long by 3 meters wide; (b) a rim angle of 90 degrees and a focal length of 0.80 meter; (c) a concentrator surface reflectance of 0.85; (d) a RMS slope deviation of the concentrator surface from the ideal shape of 0.25 degree; (e) a RMS tracking error of 0.25 degree; (f) an 8 cm diameter absorber tube with a solar absorptance of 0.85; and (g) a vacuum envelope with a solar transmittance of 1.0. The solar flux data used for the calculations were recorded by Desert Sunshine Exposure Test Inc. near Phoenix, Arizona. The data were for clear days. Therefore, in terms of available flux, the predictions are for maximum values.

Flat Plate Collectors -- A schematic of a flat plate collector and the elements of the computer program developed to analyze it are presented in Figures 5 and 6. The program uses the pertinent geometrical, environmental and operational parameters of a particular collector design configuration and computes the desired thermal performance parameters. This computer program can be utilized to obtain the predicted performance for collectors using both selective and non-selective absorber surfaces and also for predicting the effects on performance of using one or more transparent covers. The effects of wind and of varying solar incidence angle can also be analyzed.

To treat transient conditions and non-uniform temperature distributions, the collector is subdivided into a number of physical elements or nodes. A typical subdivision is indicated in Figure 5. The temperature of each node is computed as a function of time using a conventional technique in which the rate change of temperature of each node is related to its present temperature and the temperatures of the neighboring nodes.

The solar input to each element is obtained by an analysis of the reflection, transmission, and absorption of energy in the solar spectrum by the system of covers over the absorbing surface. This analysis can be carried out taking into consideration the two components of polarization, the reflection of each cover-air interface, the absorption of each cover and the absorption and reflection by the absorber. The program is then able to treat combinations of specular and/or diffuse conditions of the solar flux and absorber plate reflection. The reflection, absorption and transmission of the direct and diffuse components of the incident solar flux are analyzed separately and then the results combined to obtain the total heat absorption.

An example of the results which can be obtained are plotted in Figure 7. The instantaneous and accumulated efficiency and the temperature of the fluid leaving the collector are plotted against the time of day. The solar flux used for the calculation depicted in Figure 7 is from measurements made on 15 March 1972, at Phoenix, Arizona.

The collector analyzed has a single glass cover and a selective absorber coating with a solar absorptance of 0.9 and an infrared emittance of 0.1. The collector was assumed to be at a uniform temperature of 21°C at sunrise (6:00 a.m.) and the storage temperature, which is also the collector fluid inlet temperature, was assumed to be 71°C throughout the day. A no-flow condition was assumed until the temperature of the absorber at the fluid inlet end was 5°C greater than the fluid inlet temperature, i.e., 76°C. Under the assumed conditions, this occurs at approximately 8:00 a.m.

The instantaneous efficiency rises from a value of zero prior to circulation to a peak shortly after 12:00 noon. The slight lag in efficiency is due to capacitive heat storage in the collector components. At the end of the day, the accumulated or integrated efficiency (the total heat added to the fluid divided by the total solar energy falling on the collector) is seen to be approximately 10 percent less than the peak value of the instantaneous efficiency.

References

1. "Research Applied to Solar-Thermal Power Systems", Semi-Annual Progress Report No. 2 (1 January 1972 to 30 June 1973). Report NSF/RANN/SE/GI 34871/PR/73/2.

2. "Dynamic Conversion of Solar Generated Heat to Electricity", NASA CR-134724.

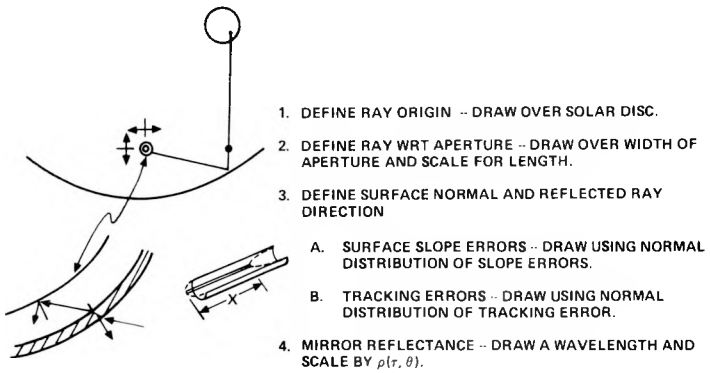


Fig. 1 – Numerical Ray Trace for Concentrating Collectors

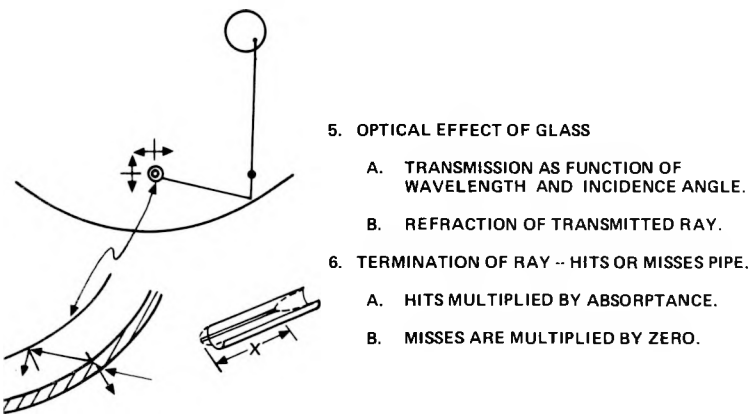


Fig. 2 – Numerical Ray Trace for Concentrating Collectors

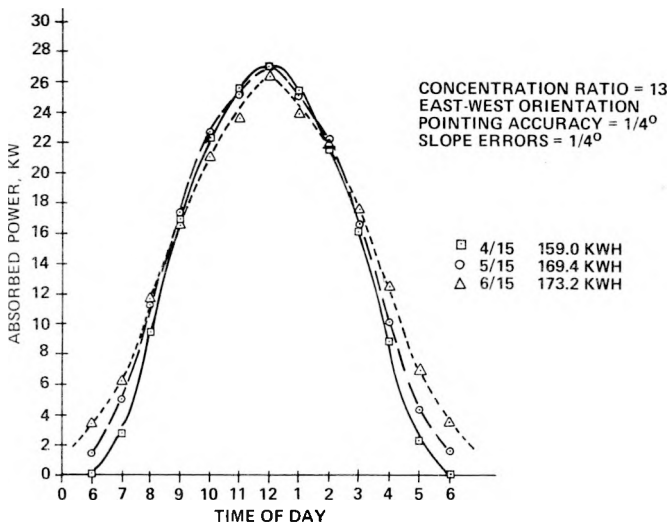


Fig. 3 – Typical Daily Performance of a Parabolic Trough Collector

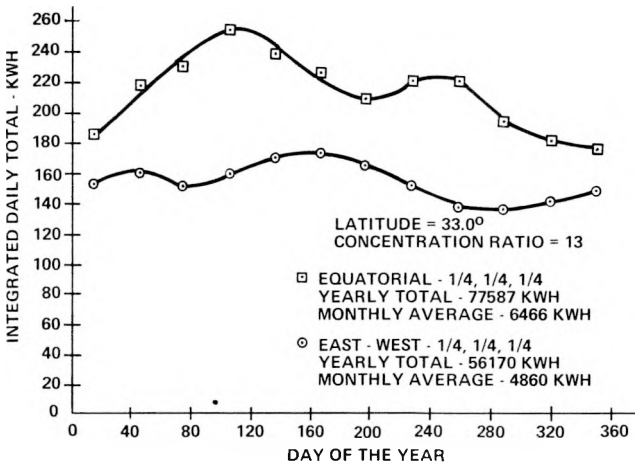


Fig. 4 — Typical Yearly Performance of a Parabolic Trough Collector

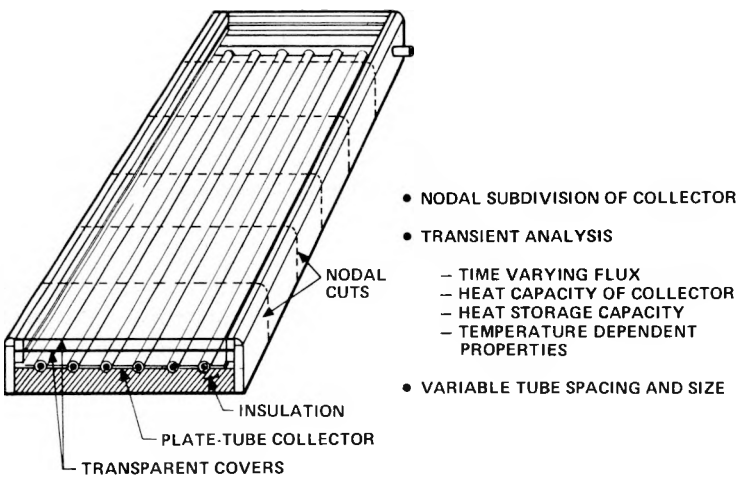


Fig. 5 — Flat Plate Collector Analysis

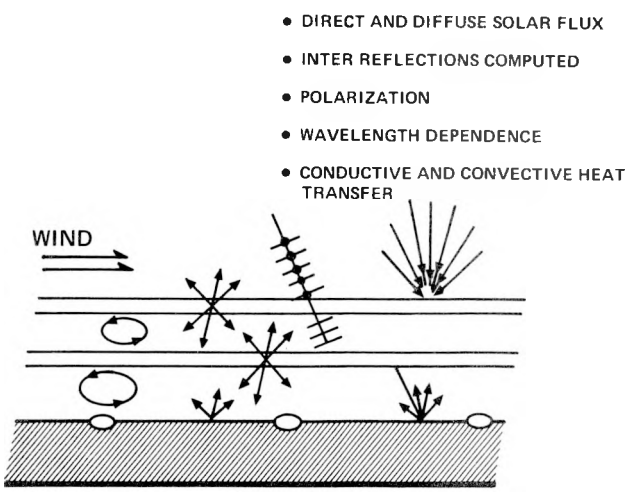


Fig. 6 — Flat Plate Collector Analysis

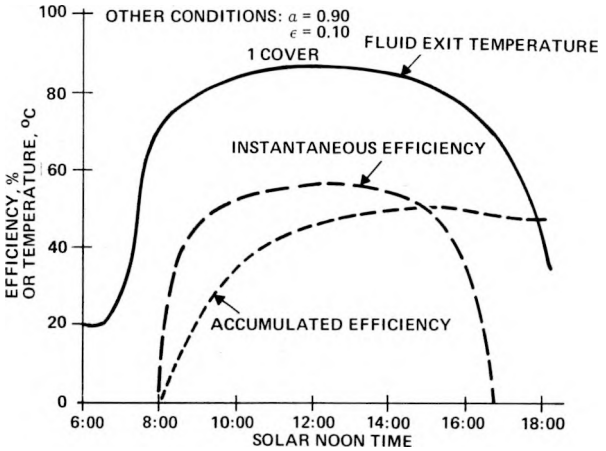


Fig. 7 – Performance of Flat Plate with Selective Surface and One Cover

DISCUSSION

Question (Bruce G. Nimmo, Florida Technological Institute): I recall a paper out of the University of Wisconsin, presented at the Detroit ASME meeting last year, which indicated that transient analysis of flat plate collectors did not differ by much from classical steady-state models. Have you also found this to be the case with your transient model?

Answer (J. W. Ramsey, Honeywell, Inc.): We have compared the performance for steady-state conditions as predicted by the classical models and the code described in the presentation. The two results are in good agreement. It is also believed that, for relatively slow changes in solar flux, inlet temperature, and ambient temperature, a series of steady-state calculations will give a reasonably accurate performance prediction.

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THE THERMAL COLLECTOR MODEL IN THE U OF P SOLAR HEATING/COOLING/ELECTRIC POWER SYSTEM COMPUTER SIMULATION PROGRAM

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Philadelphia, Pennsylvania

A very generalized, but detailed solar heating/cooling/electric power system model has been developed. In its current status, it represents the functions illustrated in Fig. 1, except for the waste digester, the fuel cell, the heat engine, and the vehicle battery charger. It contains, although not specifically shown, a heat pump for heating/cooling purposes. The purpose of the model is to facilitate design trade-off studies and research tasks, e.g. to evaluate the potential impacts of changes of system parameters on the thermal or electrical energy deliverable in realistic system operation with its interplay of empirical solar energy and load functions. Since the latter function can be a dependent variable of the former, as in the case of a building heating load, this connection can be handled either through an internal simplified model or through use of external detailed models with transfer and synchronous use of the resulting load data, e.g. via tape.

Since such a program of adequate detail is extensive, it has been organized as a group of subprograms where each subprogram represents a functional subsystem or a part of such a subsystem. This permits easy change of system design, replacements of subsystems by units of updated designs or different types, etc. Also, to fulfill the task, all parameters of potential interest for study have been made variables in the program, and a substantial number of operating options have been incorporated. The most important ones of these include single runs or continous runs over desired time periods with selectable time intervals down to 10 min., and carry-over of system status, and print-out of interval data, daily totals, or period totals; use of given solar radiation data or US Weather Bureau tapes; evaluation of direct and indirect insolation; operation with spectrally dependent variables or weighted average values.

An important aspect in the evaluation of solar collector performance is the evaluation of the incident radiation. The program currently operates in local solar time, with conversion to local standard time planned. From this the values of airmass (incidence angle horizontal surface), incidence angle on an arbitrarily oriented surface, azimuth angle,

and sunrise and sunset on both surfaces are determined, using latitude, surface tilt and rotation angles, and solar declination computed from calendar date or inputted directly (Fig. 2). The insolation on the arbitrary surface can be determined from the extraterrestrial radiation, which is stored in the program as absolute spectral distribution in 10 μm wavelength intervals according to NASA data [1], by modification for atmospheric absorption and scattering [2], if the atmospheric constants, including dust content and precipitable water vapor, are known. Alternately, available insolation data may be used. Since these generally consist only of total horizontal insolation at hourly intervals, the total insolation is seperated into direct and indirect components by use of the Liu-Jordon relationship. [3] The latter has been derived for daily totals only, but is here tentatively applied to hourly data in the absence of a better method. The direct component is adjusted for the incidence angle, while the indirect radiation is tentatively treated as constant. Problems have been encountered only at high airmass values, where the total normal radiation flux (direct plus indirect) has reached excessively large values. In these cases, the total normal flux has been limited essentially to 85% of the extraterrestrial radiation, with 16% indirect radiation. In case of spectral computations, the magnitude of the direct normal component is used to obtain the total precipitable water content of the atmosphere for given ozone and dust content, and from this the solar spectral distribution. Tentatively, the same spectral distribution is applied to the indirect radiation.

The task of evaluating thermal collector performance is essentially one of analyzing the energy flux, which includes the mechanisms of reflection, absorption, infrared radiation and conduction/convection (Fig. 3). The optical properties of any element can be inputted as transmittances, reflectances, or absorptances, (2 of these quantities required for each element). Alternately, the reflectivity of each optical surface may be given, permitting evaluation of optical coatings on the windows, with the possibility of differing coatings on both surfaces (Fig. 4). Further, the effective reflectivities under varying incidence angles can be determined, when the refractive indices of the bordering materials are given. In this case, the incident light is assumed to be circularly polarized and is split into a normally and a parallel polarized beam which are individually followed through the entire system to the collector. Finally, in case of spectrally varying optical properties, the weighted

average values can be determined by use of the aforementioned spectral distribution. It may be noted, that the multiple optical paths through a multi-element system lead to infinite series for all optical properties (Fig. 5). These are, however, exactly expressible by analytic functions. Also, the optical properties of two or more adjacent elements, including gap, can be expressed as absorptance, reflectance, transmittance of the combined group, permitting easy set-up of the mathematical expressions for n elements, n>3. Thus, the total effective reflectance from the entire collector system is obtained, as well as the fractions of the incident energy which are absorbed in the absorber surface and in each window.

Similar treatments are carried out for the emmittances. Where the weighted averages are not given, they can be determined from the spectral emissivities and the Planck distribution determined for the element temeprature (Fig. 6).

Finally, the heat transfer coefficients (U-factors) for conduction and free convection in the gap between the optical elements and to the outside are evaluated by standard themodynamical methods. Grashoff (N_{gr}) and Nusselt (N_{nu}) numbers are evaluated for horizontal or vertical gaps with any gas according to Fig. 7, where k is the thermal conductivity, d the element spacing, g the gravity, ρ gas density, μ the viscosity, and h the height of the gas space for vertical systems. T_{ave} is the gas temperature, taken as the average temperature of the 2 surfaces boundaring the gas space, while ΔT is the temperature difference between these 2 surfaces. For tilted collectors, an interpolation between the U-factors for the horizontal and the vertical system is carried out (Fig. 8).

Having determined all these coefficients, a system of n equation for the energy balances on each of the n elements of the system can be set up. In this system, which forms a tridiagonal determinant, the temperature of the n elements are the unknowns. This system can be expressed in energy fluxes (power) for a steady state solution, or in total energy transferred in a given time interval, including the energy stored by the heat capacity of each element, for the transient solution (Fig. 9). Both options exist in the program. Since the latter has been linearized, its solutions can deviate from the true transient, so that it is important to choose the evaluation time intervals adequately small compared to the transient time.

Solutions for the equation systems can be obtained in various modes: 1. given collector temperature; 2. given energy removal from the collector; 3. energy transfer through absorber wall to a fluid at given massflowrate and inlet temperature, and 4. energy transfer to a fluid at given massflowrate through a heat exchanger of given configuration to a secondary fluid of given inlet temperature (e.g. room air).

In the last case, the single heat exchanger can be replaced with a network of series and parallel connected heat exchangers, which can include the piping losses.

The program has been successfully employed in its various operating modes, individually and as part of the total system program, for various collector research studies and for systems performance evaluations over various time periods, up to a year. A typical hourly run over a season for a heating cooling system including storage control functions, using both Weather Bureau data and thermal load data on tape, and using weighted average optical data, has been found to cost $30.- to 50.- in computer charges. Making spectral runs, however, increases the costs substantially.

References

1). Thekaekara, M.P., Solar Energy 14, pp. 109-127, Jan. 1973
2). Moon, P., J. Franklin Inst. 230, pp. 583-617, Nov. 1940
3). Liu, B.Y.H., and Jordan, R.C., Solar Energy 4, pp. 1-20, Fig. 7, July 1960

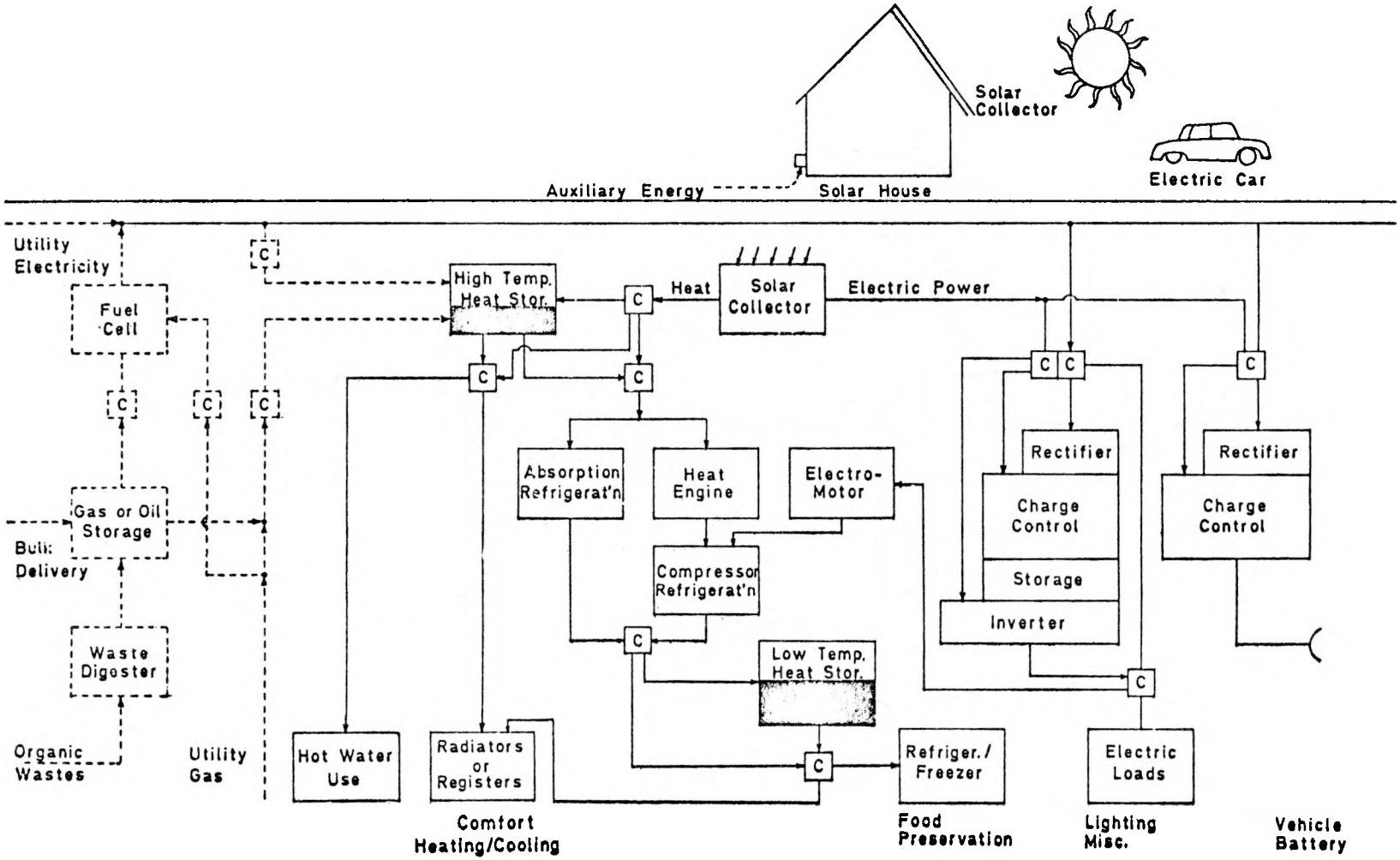


Fig. 1 — Diagram of University of Pennsylvania Solar Heating/Cooling Electric Power System

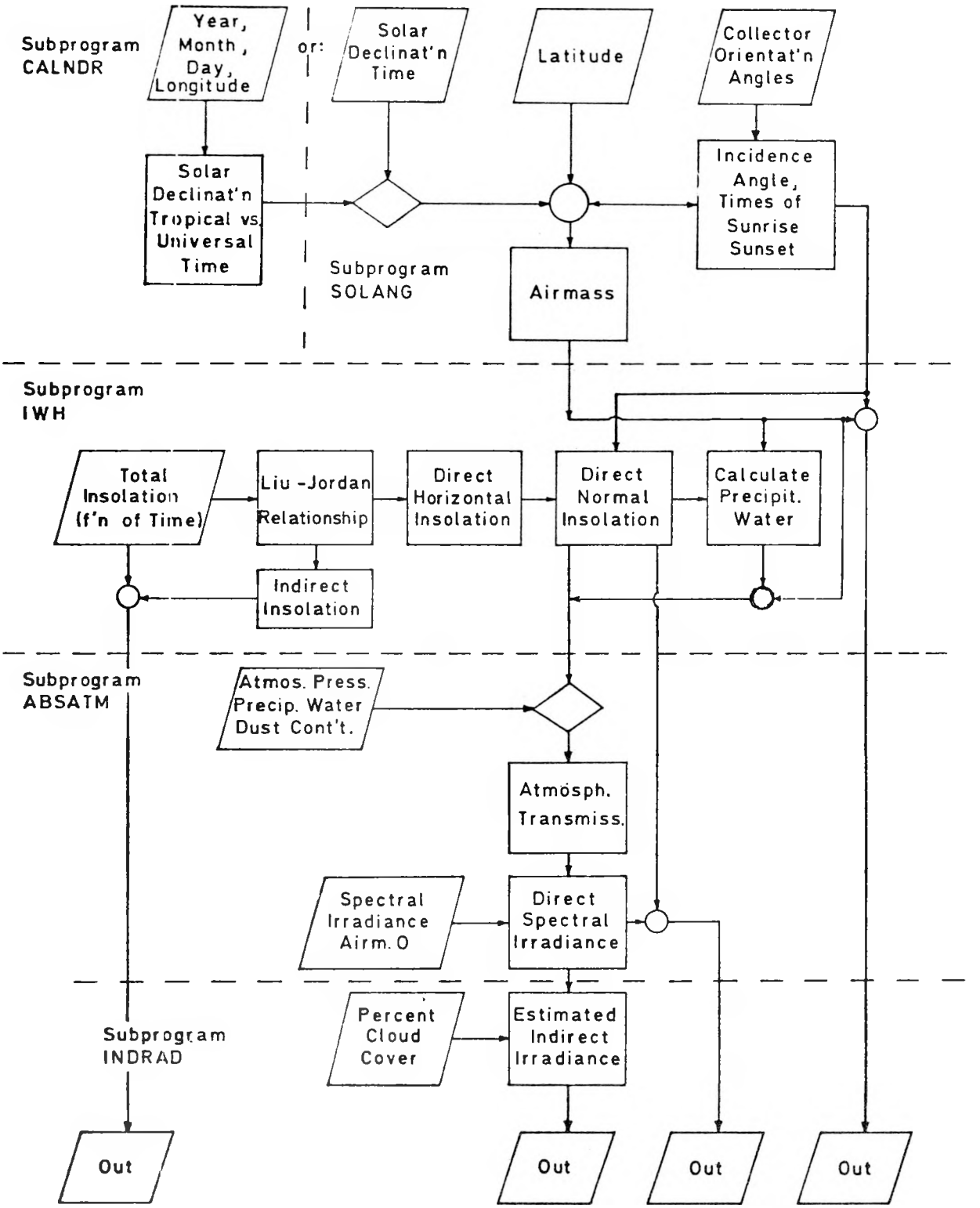


Fig. 2 — Computation Method for Evaluating Incident Solar Radiation

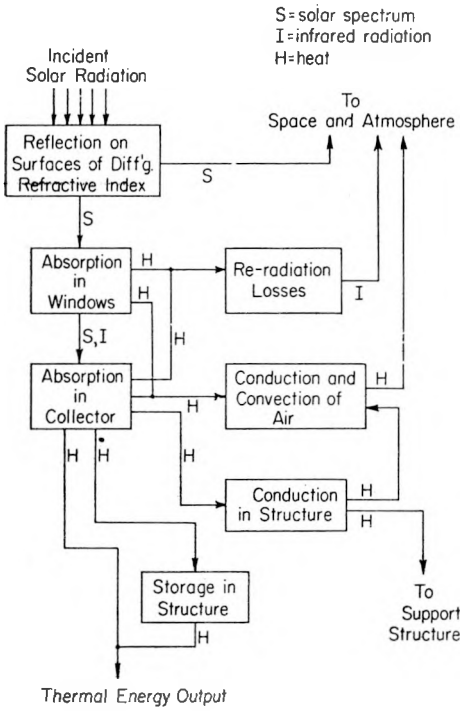


Fig. 3 — Energy Flow in Flat Plate Collectors

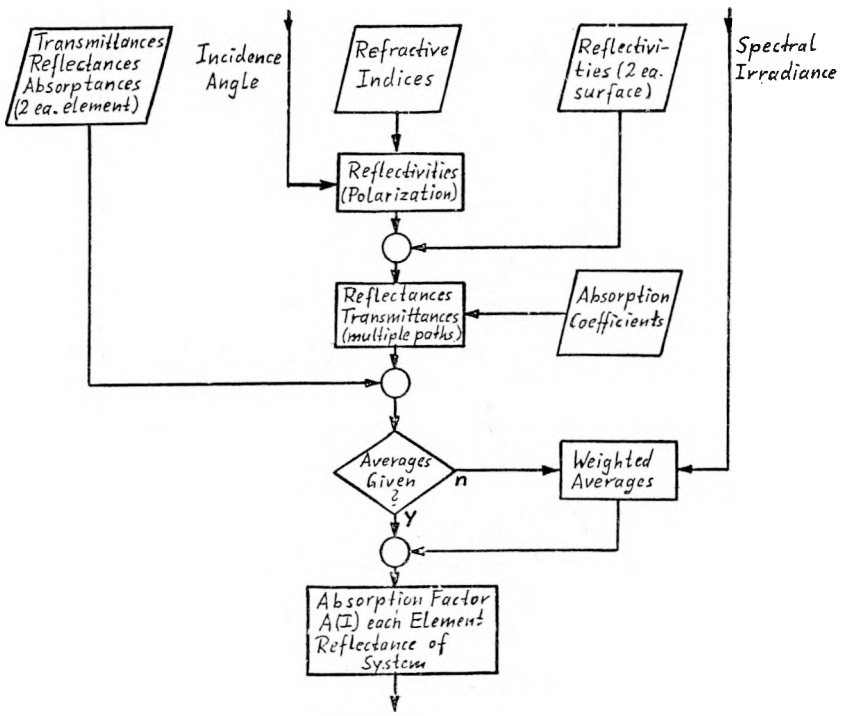


Fig. 4 — Computation Method for Collector Optics

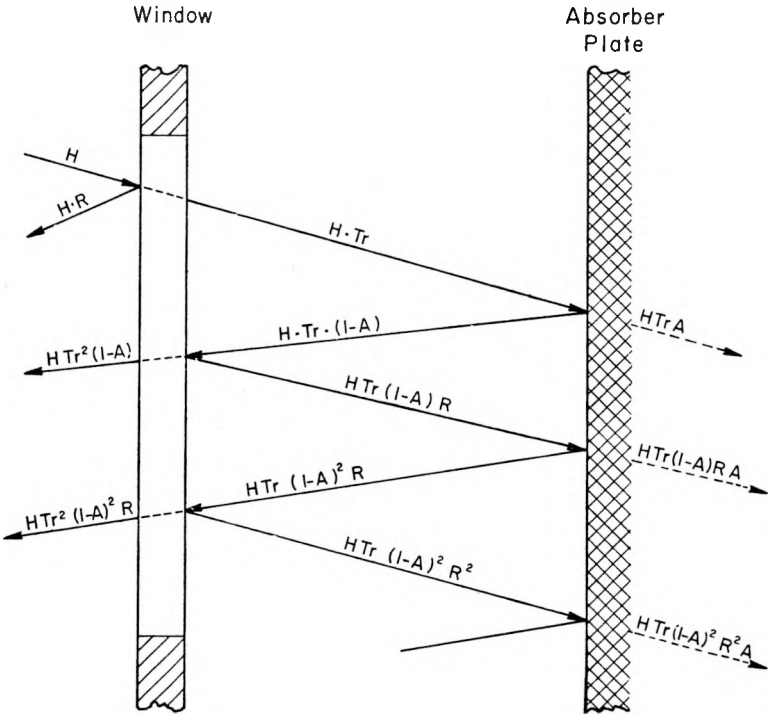


Fig. 5 – Multiple Reflections in a Single-Glazed Collector

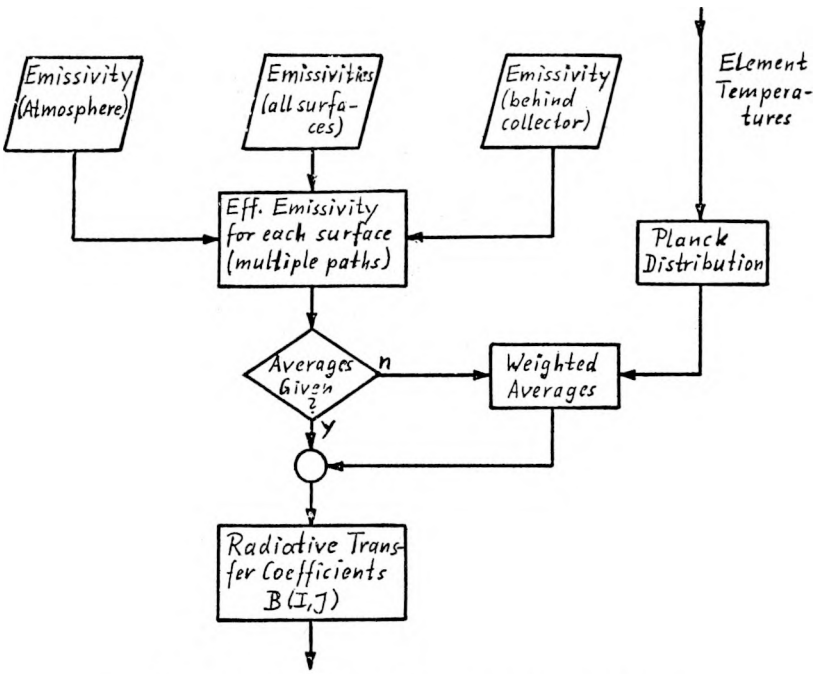


Fig. 6 – Computation Method for Radiative Transfer

$$U_V(I,J) = \frac{K(I,J)}{D(I,J)} \left[N_{NU}(I,J)\right]^{AM(I,J)}$$

$$U_H(I,J) = A(I,J)\,\frac{K(I,J)}{D(I,J)} \left[N_{GR}(I,J)\right]^{AM(I,J)}$$

$$N_{GR}(I,J) = G\left(\frac{\rho(I,J)}{\mu(I,J)}\right)^2 \frac{D^3(I,J)}{T_{AVE}(I,J)}\,\Delta T(I,J)$$

$$N_{NU}(I,J) = A(I,J)\left[N_{GR}(I,J)\right]^{AM(I,J)} \left[\frac{H}{D(I,J)}\right]^{BM(I,J)}$$

$$\rho(I,J) = \rho_{GAS}(T_{AVE}(I,J);\quad \mu(I,J) = \mu_{GAS}(T_{AVE}(I,J);$$

$$A(I,J) = F(N_{GR}(I,J));\ AM(I,J) = G(N_{GR}(I,J));\ B_M(I,J) = H(N_{GR}(I,J));$$

Fig. 7 – Functional Relationships for Conduction/Convection in Gas Spaces

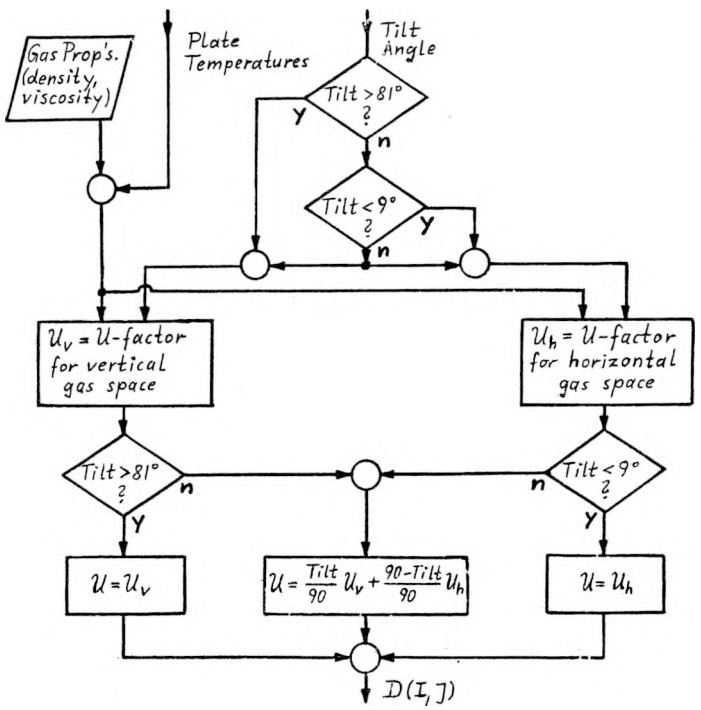


Fig. 8 – Computation of Heat Transfer Coefficients for Tilted Collectors

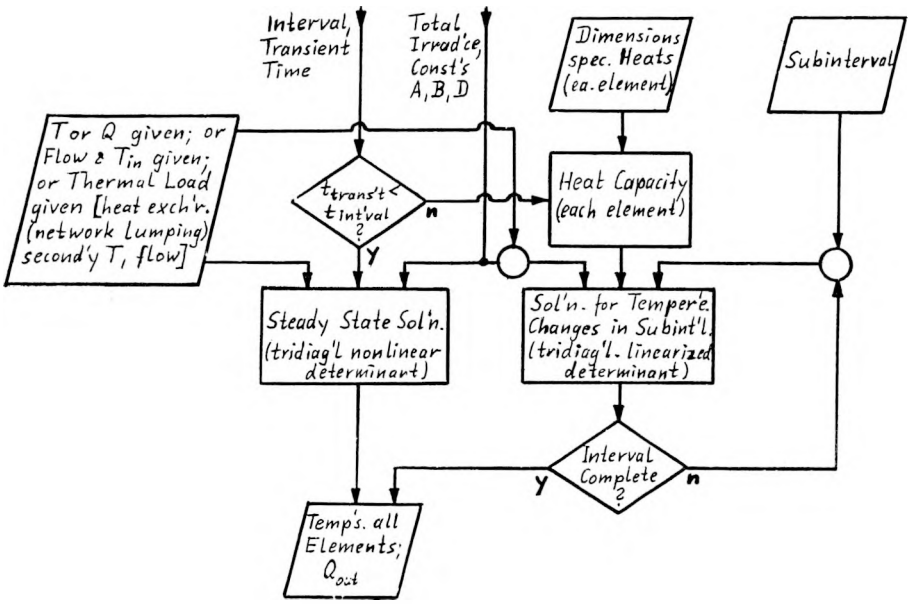


Fig. 9 — Computation of Collector Temperature and Output by Steady-State or Quasi-Transient Solution

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LOCKHEED-HUNTSVILLE SOLAR HVAC SIMULATION MODEL

P. O. McCormick

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Huntsville Research & Engineering Center
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During the period 1971-74 Lockheed-Huntsville has supported NASA-Marshall Space Flight Center in their development of a solar powered heating/air conditioning system for residential application. During this study we developed a solar HVAC system simulation computer program (Refs. 1 and 2) to perform design studies for the NASA solar demonstration unit which was built in the spring of 1974. In the summer of 1974 the National Science Foundation funded a one-year study to improve this system simulation program. The program objectives (see Table I) were primarily to make those changes which were necessary to make the program more generally applicable and easy to use by one not intimately familiar with the program.

The heart of any such program is the collector model. The Lockheed-Huntsville collector model exists in two forms: (1) as a separate program which can be used for steady state collector design and evaluation studies and (2) as a subroutine in the transient systems analysis program. The improvements (Table II) made to date on the collector program are, again, intended primarily to make it more general. The steady state model has been informally documented and an input guide has been prepared so that the steady state program is available for general use. The systems analysis program will be available in the summer of 1975.

The collector program has been compared with many sets of test data which were taken by various investigators under a variety of conditions. In all cases the comparisons have been very satisfactory. Figures 1, 2 and 3 show theory-test comparisons for three common collectors: (1) two glass covers with flat black paint; (2) one Tedlar cover with a selective coating; and (3) one glass cover with a selective coating. The most significant results are those of Fig. 2 which are for the NASA-MSFC collector (2 mil Tedlar with 2 by 4-inch reinforcing wire guide cover with a nickel black selective coating on aluminum

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[1] O'Neill, M. J., A. J. McDanal and W. H. Sims, "The Development of a Residential Heating and Cooling System Using NASA-Derived Technology," LMSC-HREC D306275, Lockheed Missiles & Space Company, Huntsville, Ala., November 1972.

[2] O'Neill, M. J., P. O. McCormick and W. R. Kruse, "The Development of a Residential Heating and Cooling System Using NASA-Derived Technology – Final Report," LMSC-HREC TR D390138, Lockheed Missiles & Space Company, Huntsville, Ala., July 1974.

Roll Bond panel). This test set-up was well instrumented and the test was essentially continuous for many days. The collector area was 40 square feet which is bigger than most test panels. The significant fact in this comparison is that the collector model accurately predicts the performances of the collector at the maximum operating temperature point (efficiency equals 0). At this point the losses (usually a direct function of temperature differences) are greatest and any inaccuracies in predicting the losses show up much more dramatically than when the collector is operating near ambient temperature.

In conclusion, results of the collector model have been compared with a large amount of data on widely differing flat plate collectors. In all cases the results have been very satisfactory. The steady state collector program has been documented informally and an input guide is available for anyone desiring to use the program. The total systems analysis program will be available in the summer of 1975.

TABLE I - PROGRAM OBJECTIVES

- Improvements to Computer Program
  - More General Application
  - Better Models for Loads, Storage, Heating, Air Conditioning, Collector
  - Reduced Computer Time
  - Refined Input-Output
- Compare Systems Analysis Results with Test Data
- Documentation
- Dissemination to Potential Users
  - Commercial/Residential Designers
  - Investigators Concerned with:
    Collector Design
    Air Conditioner Development
    Controls

TABLE II - ACCOMPLISHMENTS TO DATE

COLLECTOR PERFORMANCE PROGRAM (STEADY STATE)

- More General Application
- Easy to Use
- Improved Free Convection Calculations (Ref. 3)
- Compared with Test Data
- Available for General Use

SYSTEM ANALYSIS PROGRAM (TRANSIENT)

- Increased Flexibility
- Transient Collector Model Improvements
  - Free Convection Calculations
  - Absorber Temperature Calculations
  - Seasonal Tilt Variations

[3] DeGraff, J. G. A., and E. F. M. Van Der Held, "The Relation Between the Heat Transfer and the Convection Phenomena in Enclosed Plane Air Layers," Appl. Sci. Res., Section A, Vol. 3, 1952, p. 393.

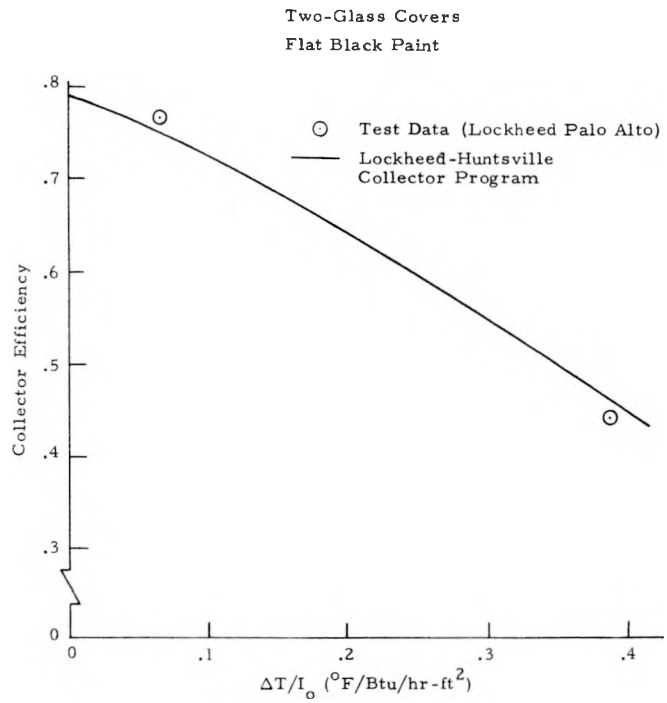


Fig. 1 – Comparison of Lockheed-Huntsville Analysis with Palo Alto Test Data

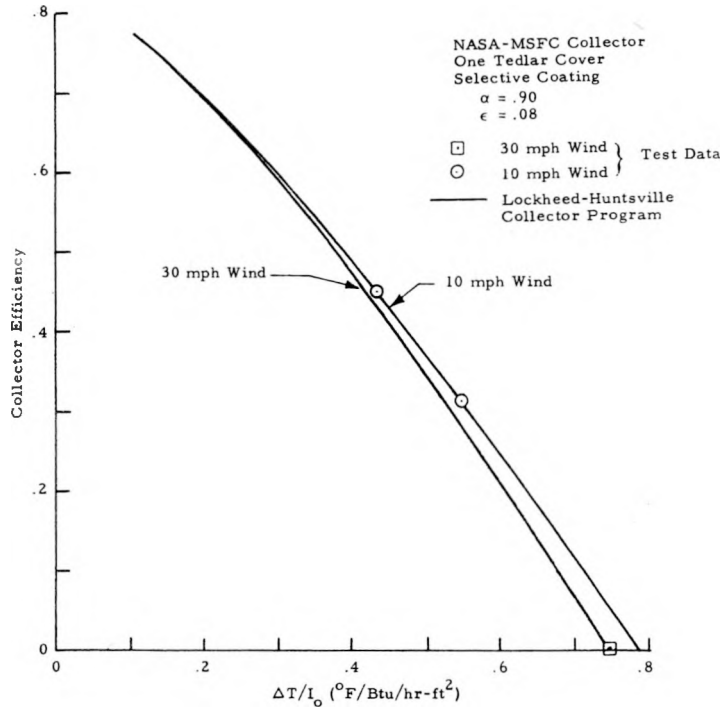


Fig. 2 – Comparison of Lockheed-Huntsville Analysis with NASA-MSFC Test Data

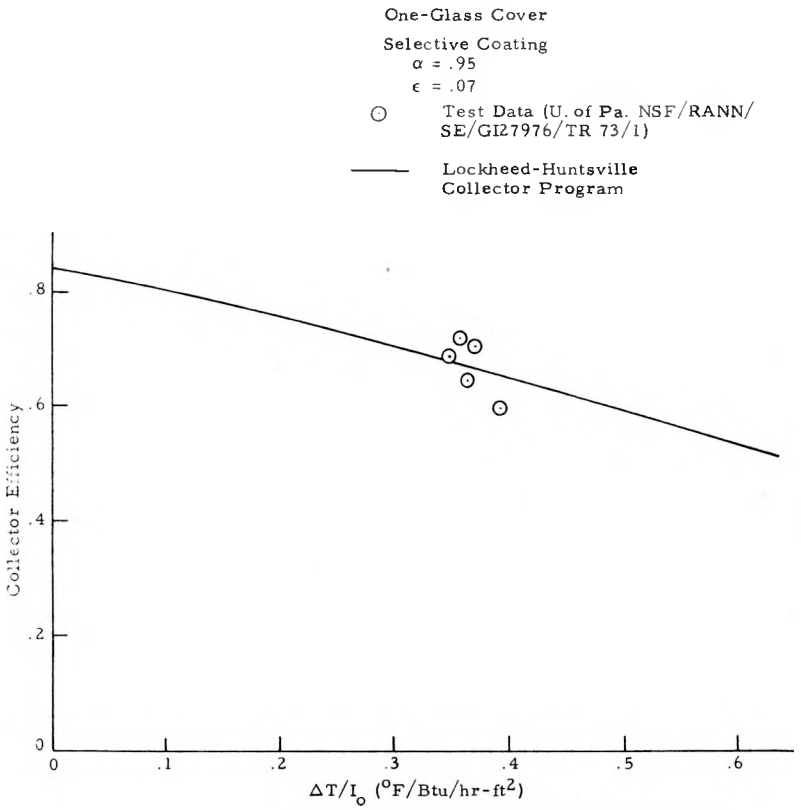


Fig. 3 – Comparison of Lockheed-Huntsville Analysis with University of Pennsylvania Test Data

DISCUSSION

Question (John Duffie, University of Wisconsin): What is the source of your improved free convection calculation? What is the nature of the correlation?

Answer (Paul McCormick, Lockheed Missiles and Space Co.): The correlation that is in there right now is by Degraff and Vanderheld, nothing new by any means, but improved over what we had before. We are in the process right now of running a computer program that was developed for a NASA free convection experiment in space to get us a better correlation of the flat plate free convection terms as a function of angle, Rayleigh number, etc.

HYBRID SIMULATION OF SOLAR HVAC SYSTEM FOR HOUSE RETRO-FIT DESIGN

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Introduction

It is the objective of the initial phase of this work, which is supported by the National Science Foundation (Grant #GI-43896), to develop a prototype hardware system capable of simulated solar heating ventilating and air conditioning performance when associated with a residential building. It is also an objective to provide a test bed for computer solar system design model verification. This simulated hardware approach can provide a very flexible and inexpensive method for determining the operation of a proposed solar heating system on a specific dwelling. Further, the system can be tailored to the specifications predicted by a particular computer model and the performance that would be realized if a full-scale solar system had been applied to the house may be observed.

System Concept

To appreciate where the conceptual approach for this work fits into the hierarchy of current solar energy system investigations, it is appropriate to briefly mention the alternative schemes open to the solar house heating and cooling researcher.

The most obvious approach for establishing system effectiveness is to retrofit a full scale solar heating system to the existing building of interest. Clearly this is a desirable approach in the sense that the responses to the load and environment will be totally realistic. The major disadvantages to this approach are that a) it is costly, and b) it is somewhat difficult to modify or change after the fact of the actual installation.

A second approach in common use is to use total computer simulation to determine the effectiveness of the proposed solar system on a particular dwelling.

The major advantages are a high-degree of flexibility, relatively inexpensive, and results can be obtained representative of a long period of time in a matter of a few moments. This requires, of course, that adequate weather and load data for the location were available. The predominent disadvantage to this approach is that multiple assumptions in the modeled environment are required. It is, for example, extremely difficult to model the impact of the life-style of the particular inhabitants of the house on the energy demands. Further, the effects of microclimate characteristics may introduce significant variations from conditions that exist where the weather data was collected. Insolation data, in fact, may have been collected at a considerable distance from the location being studied, due to the historic scarcity of such instrumented sites.

Between these two extremes, that is, the totally modeled environment or the complete design and installation of an actual solar HVAC system is an approach I chose to call hybrid simulation. The major advantages of this approach are that the loads, namely the house, the inhabitants, and the environment, including whatever micro-climate conditions exist in the immediate vicinity, are real.

The components of the solar HVAC system, namely the collector, storage tank, and control system, are simulated. The loads and the simulated HVAC are coupled together within the actual structure under investigation. The equipment which has been designed to simulate the solar HVAC system is quite inexpensive and relatively flexible. The major disadvantage with this approach is that it does operate in real time, that is, to collect a month's data takes one month.

The relation between these three approaches are shown in Figures 1, 2, and 3, respectively.

System Description

The system design is rather straightforward in terms of circuitry and instrumentation.

A block diagram of the interface between the existing HVAC system and the simulator is presented in Figure 4. Figure 5 shows a simplified logic diagram of the analog circuitry. The loads for the simulator are taken from the actual HVAC system currently installed in the house. When the house needs heat (for example) the furnace goes on and this energy is extracted from a simulated storage shown as the microcoulometer at the bottom of Figure 4. On the other hand, when energy is available, the solar cell, acting as a collector, receives this energy and transfers it to the storage. The relative size of the collector can be adjusted by the amplifier shown as A. Gain settings representing collector areas from 300 ft^2 to in excess of 2000 ft^2 are easily accommodated. Hence, a very flexible selection of input function is available. The microcoulometer storage unit is a highly stable and accurate long-term integrator, able to maintain 1-2% accuracy over a 24 hour period continuously. Assume for a moment that the particular house in question has a 120,000 BTU furnace operating at 70% efficiency. If the storage is adjusted to simulate 1500 gallons of water, for every hour of furnace operation the temperature will drop 3.73°C. Energy is put into the storage at a rate depending on the intensity of the sun (the insolation) and the setting of the collector size amplifier. In the simplest form, one can see that the actual house load demands takes energy out of the simulator storage and the true insolation level available puts energy into the storage. Appropriate constraints are added to the simulator to represent the efficiency of the collector, leakage of the storage tank, efficiencies of the HVAC system, etc. Figure 5 shows additional characteristics considered, specifically, the change in efficiency due to inlet water temperature as the tank increases in energy and ambient factors such as wind and external ambient temperature.

The system is quite simple to install for operation. Figure 6 shows a sketch of a typical unit in a portable mode, and Figure 7 shows the actual simulator. Table I shows the parameters recorded by the system.

Results

A day results are shown for October 24th 1974. This data was selected because all of the functions took place separately without overlap, so that the performance can be seen clearly. In Figure 8 the little shaded square between 7 and 8 o'clock with vertical lines, shows the only time that the furnace went on during this particular day. Note that the inside temperature rose slightly from 7 to 8 o'clock in response, and that the tank temperature fell commensurately during the same period. From 8 o'clock to 9 o'clock the tank temperature held constant, and though the sun was up (the large dotted line envelope) the pumps had not yet come on. At approximately 9 o'clock the temperature in the collector rose sufficiently to turn on the pumps and the tank temperature can be observed rising throughout the day until about 1500 hours, at which point the upper temperature capacity of the system was reached and the high temperature cut-out took over, holding the tank temperature at the 99.2°. From this point on, all the energy available is lost (not collected). This is shown by the large hatched area. At approximately 1700 hours the pump turned off as the sun dropped to the horizon.

Data presented in this report considers operation in the "open loop" mode only. This is equivalent to holding the collector efficiency constant throughout the day. Data in the "closed loop" mode of operation is currently being collected.

Early analysis of performance indicates that the system can respond to insolation and load conditions in a manner very similar to what one would except from the actual solar HVAC operation. Long-term energy balances with respect to inputs, loads, and time varying demands, are obtained to accuracies in the order of 5%.

Initial operation of the system began by employing a "rule of thumb" of 1/2 the floor area of the house for the collector area, and 1 1/2 gallons of storage tank capacity per square foot of collector.

Two facts were quickly obtained: 1) results calibrated the house at 19,500 BTU/degree day, and 2) that is not the rule of thumb for Southern California.

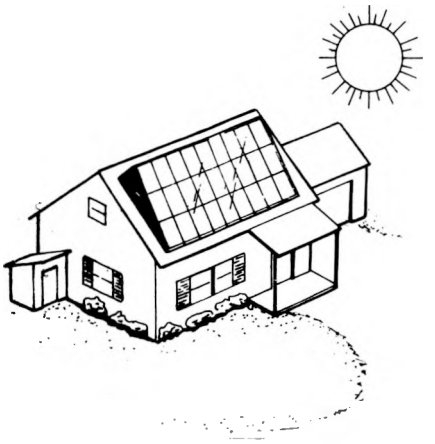
The collector area was then reduced through additional runs to 770 ft^2, 500 ft^2, and 350 ft^2. Storage tank capacity was also modified during this period.

The results of some of these runs are still being analyzed. However, the simulator appears to offer the desired flexibility for matching system design configurations to the actual building and environment.

TABLE I. RECORDED PARAMETERS

	ITEM	UNITS
1.	HVAC operating time	minutes of operation
2.	Outside ambient temperature	^{o}C
3.	Outside wind speed	miles/hour
4.	Storage tank temperature	^{o}C
5.	Pyranometer	Langleys
6.	Collector	area (ft^2)
7.	Storage	gallons
8.	Furnace, operating load	BTUs/hour
9.	Solar cell	mw/cm^2
10.	Inside temperature	^{o}C
11.	Pump	on/off
12.	Low tank temperature (30^{o})	^{o}C
13.	High tank temperature (99^{o})	^{o}C

I. FULL SCALE SOLAR HEATING SYSTEM



ADVANTAGES

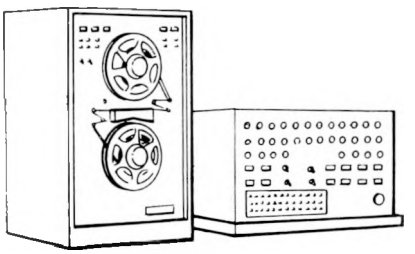
- TRUE RESPONSES TO LOADS AND ENVIRONMENT
- TOTALLY REALISTIC

DISADVANTAGES

- COSTLY
- DIFFICULT TO MODIFY
- INFLEXIBLE

Fig. 1 – Levels of Approaches of Solar Energy Application to Home Heating and Cooling Research. Full-Scale Heating System

II. TOTAL COMPUTER SIMULATION



ADVANTAGES

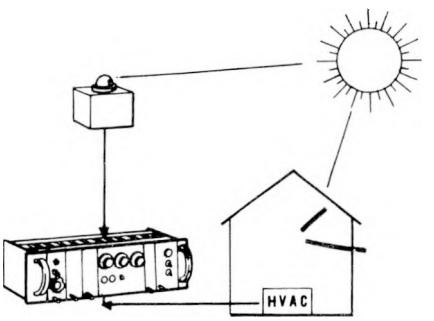
- FLEXIBLE
- RELATIVELY INEXPENSIVE
- NON-REAL TIME

DISADVANTAGES

- MULTIPLE ASSUMPTIONS
- "MODELED ENVIRONMENT"

Fig. 2 – Levels of Approaches of Solar Energy Application to Home Heating and Cooling Research. Total Computer Simulation

III. HYBRID SIMULATION



ADVANTAGES

- REAL LOADS AND ENVIRONMENTS
- INEXPENSIVE
- FLEXIBLE

DISADVANTAGES

- REAL TIME

Fig. 3 – Levels of Approaches of Solar Energy Application to Home Heating and Cooling Research. Hybrid Simulation

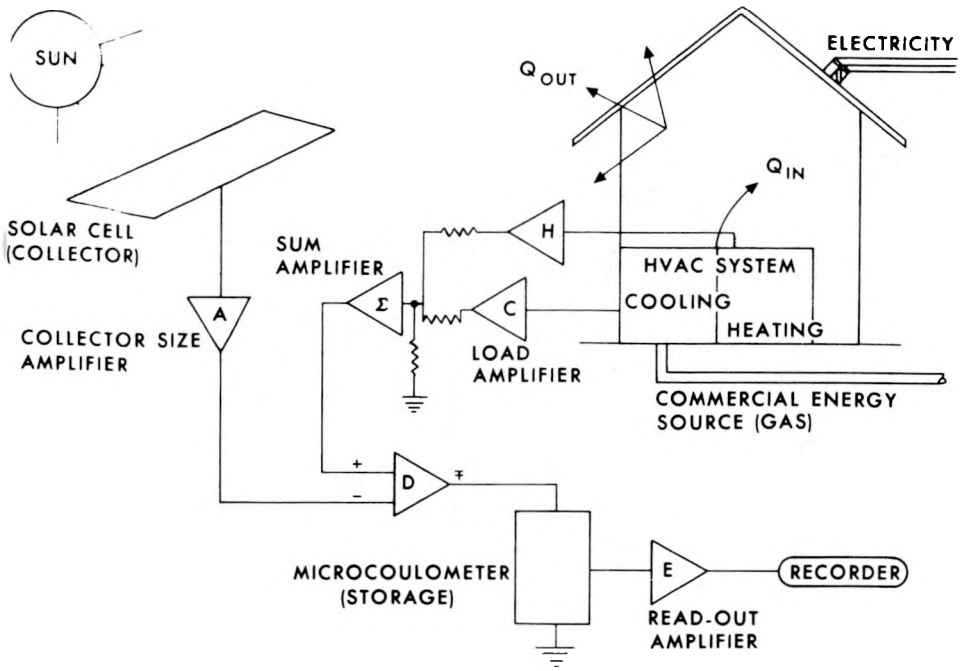


Fig. 4 — Simple House-Simulator Interface

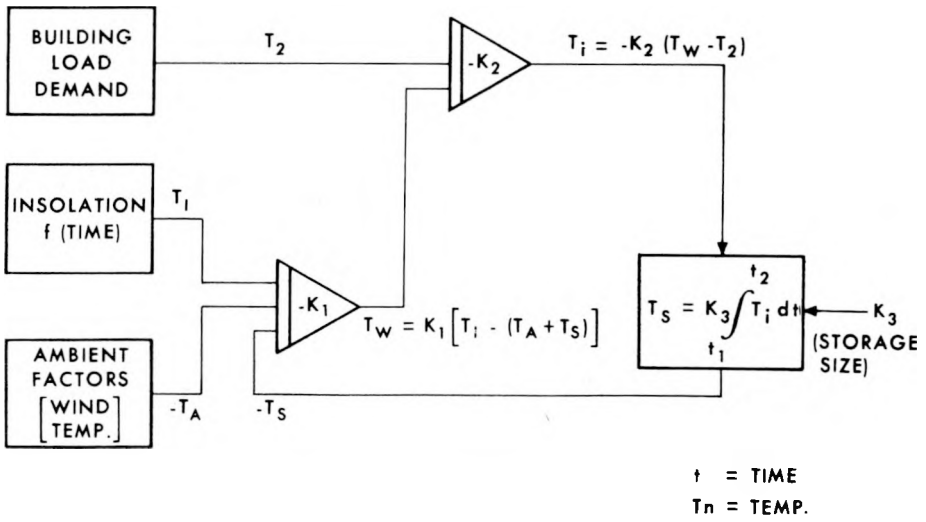


Fig. 5 — Flow Diagram of the Analog Circuitry (Simplified)

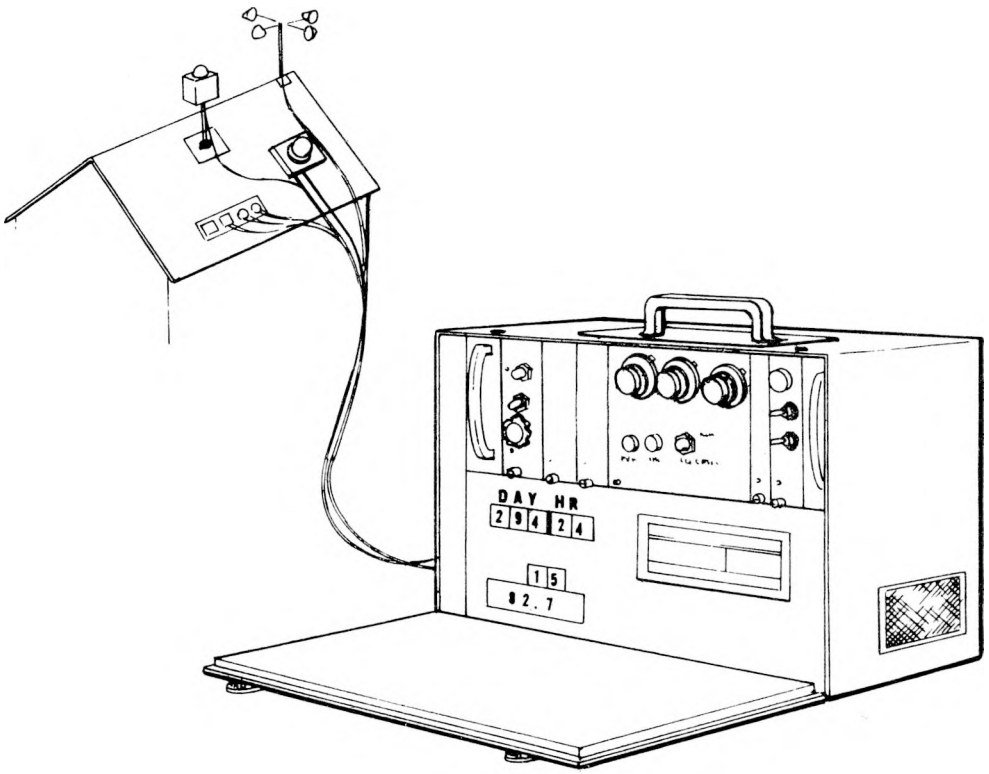


Fig. 6 -- Conception of Portable Field Unit

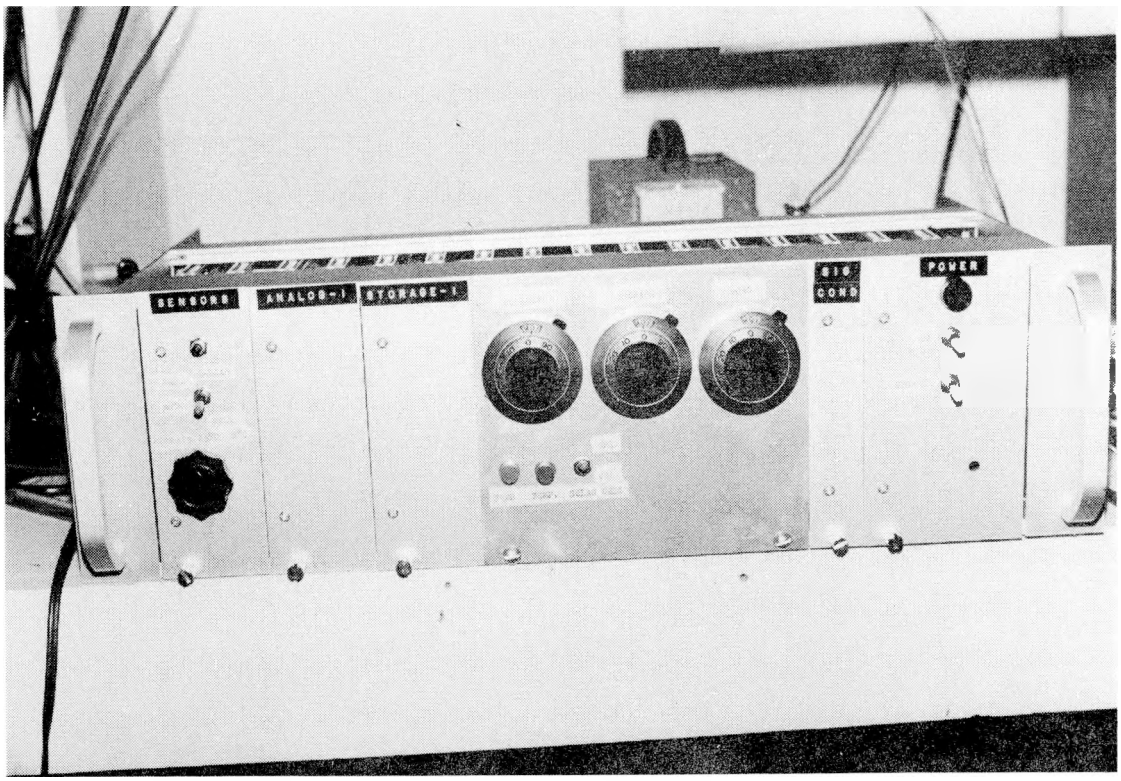


Fig. 7 -- Actual Simulator

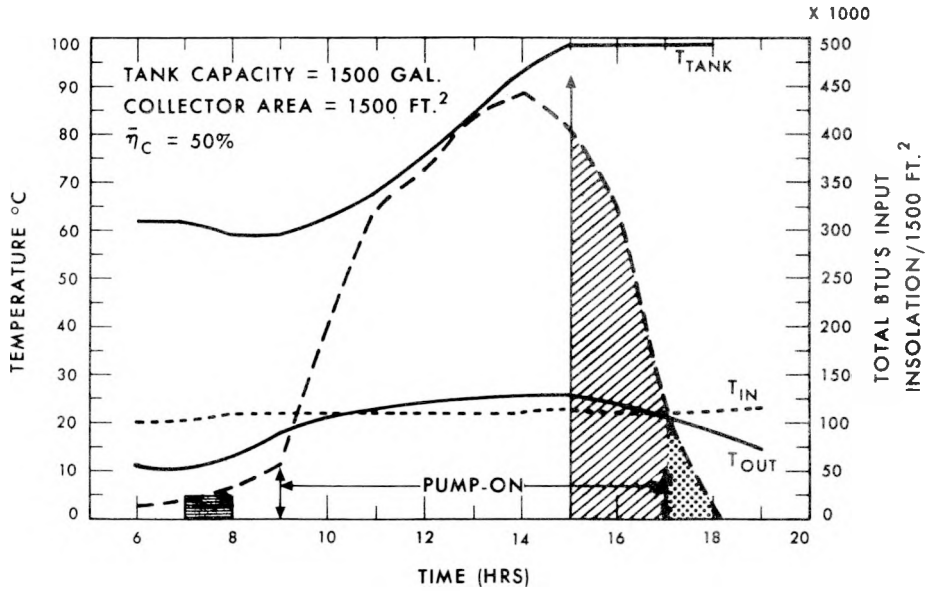


Fig. 8 -- Performance Output for a Day -- October 24, 1974

DISCUSSION

Question (Paul T. Roth, EPA Data Processing): How does one apply for instrumentation by your organization, or what does that equipment cost to own or lease?

Answer (Robert J. Schlesinger, Jet Propulsion Laboratory): I think I can probably provide one. My guess is that the cost is on the order of about $5,000. That would include the instrumentation package on the roof and the data recording system. We have to have some discussion on whether you want a digital printout or magnetic tape. Let's put it this way: we are not exactly in mass production on these things, so we would talk in terms of custom design, depending on the person's requirements.

Question (F. John Allen, Garrison, N.Y.): We have heard claims of Harry Thomason of Thomason Solaris Homes for a number of years that his system is inexpensive and allegedly works. Why has there not been a total system analysis of one of his actual homes that are in use? Is such a study planned?

Answer: I think that when the house is operated from an actual solar collector, it would be inappropriate to use a package like this. You would want an instrumentation package on the house. That should be done, but the approach would not require simulated storage. He has real storage and a real collector. A data instrumentation package would be the appropriate approach there, I believe.

S21111

MODERATELY CONCENTRATING (NOT FOCUSING) SOLAR ENERGY COLLECTORS

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Houston, Texas 77004

Introduction

This work is being performed under NSF/RANN sponsorship (NSF Grant GI-41003) at the University of Houston and the NASA Johnson Space Center. We are currently at about the mid-point of a one-year program.

Figure 1 illustrates how our basic concept differs from the conventional flat plate collector. Moderate concentration (possibly as high as ten-to-one but more probably three-to-one) is achieved by installing mirror-like surfaces above the actual absorber plate to redirect incident radiative energy to the plate. Our intent is to investigate the feasibility of stationary, low cost, low maintenance collectors of this type.

The program under NSF/RANN support is limited to radiative effects. In particular we are addressing the problem of optimizing radiative performance. Under the assumption that material quality is mainly a function of cost (i.e., any optimal design will have highly specularly reflective walls and a highly spectrally selective absorber plate) this work is directed at geometry optimization. The first case of geometric configurations considered were straight, trapezoidal grooves oriented with the base plate running East-West (depicted in Fig. 1). Other possible configurations include other orientations of trapezoidal grooves (e.g., Northwest-to-Southeast for maximum efficiency in the morning (northern hemisphere)), unsymmetric grooves, or curved walled grooves.

The radiative performance of the collector as a whole can be represented by two related parameters, effective solar absorptivity, α_s', and concentration ratio, CR. These two quantities are defined below:

α_s' = ratio of the energy absorbed on the base to that energy incident on the entire collector

CR = ratio of the flux incident on the base to that incident at the opening or aperture of the collector

Note that both α_s' and CR include the effects of losses by wall absorption and non-specular reflections.

It can be shown that

$$\alpha_s' = CR\ \alpha_{SB}\ \frac{A_B}{A_C}$$

where

α_{SB} = solar absorptivity of the absorber plate

A_B = absorber plate area

A_C = collector aperture or opening area

The effective solar absorptivity is essentially the radiative collection efficiency. In the limit as the depth-to-base ratio approaches zero, α_s' approaches α_{SB}. The concentration ratio is related to the attainable absorber plate temperature. In addition, it is the quantity measured directly in the model testing described earlier in Dr. Jack Howell's presentation (Session 5).

Simulation

The current simulation is restricted to radiative effects and to direct beam incident energy. Work is currently underway to modify the model so that the effect of diffuse incident energy can be determined.

A Monte Carlo, or ray tracing, technique has been employed. For the present model this technique could represent a case of overkill, but it is felt that subsequent, more sophisticated models would require a Monte Carlo solution. The "modular" character of the program facilitates adding to the basic analogue more realistic property data, groove end losses, and alternative geometries as well as actual solar incidence.

Figure 2 illustrates the simulation parameters for the two-dimensional (infinite) trapezoidal groove. The wall is modeled as a specular - diffuse reflector. Its solar absorptivity is denoted as α_{SW} and f is the ratio of specular reflections to total reflections. The base absorptivity has already been defined as α_{SB}. The distance of the base below the opening is denoted as D. The base width is B. Actually only the ratio D/B is required. Two angles are required to locate the sun as shown.

In the Monte Carlo simulation as in any numerical approximation scheme accuracy must be traded against computer-run time (i.e., dollars). For the preliminary work done so far each run costs approximately $1.00.

Results

Typical results are presented in Figs. 3 and 4. Figure 3 depicts the effective absorptivity versus the depth-to-base

ratio for various noon sun angles. The groove geometry used and its radiative properties are included in the figure. Figure 4 is a similar plot of concentration ratio for the same configuration. The point to be noted here is that as the groove gets deeper compared to its base (i.e., as D/B increases) the effective absorptivity decreases since less incident energy reaches the base due to two effects:

1. Energy is reflected out of the groove before reaching the base, or

2. The increasing number of wall reflections required to reach the base causes increased losses due to wall absorption.

Also, as D/B increases the concentration ratio initially increases due to concentration on a smaller base area. However, eventually the reduction in effective solar absorptivity becomes dominant and the concentration ratio is reduced. As the sun angle increases performance decreases, as could be expected.

Conclusion

The accepted measure of the performance of a solar collector is collector efficiency at a given collection temperature. An ideal (i.e., no cover plate, no end losses, no back losses and assuming a single value for the convective heat transfer coefficient) efficiency curve is plotted in Fig. 5 for a variety of solar collectors - two are of the conventianal flat-plate type, two are of the moderately concentrating (groove) type. The absorber plates are gray ($\alpha = \varepsilon$) and spectually selective ($\alpha_{s/\varepsilon} \cong 13$). Insolation is 350 Btu/ft^2-hr.

The purpose of this figure is to illustrate on the basis of relative ideal performance where the moderately concentrating collector fits into the overall collector picture. As can be seen, even with a gray (cheap and reliable) absorber plate the grooved collector performance approaches that of the flat-plate selective surface collector. Combining the moderately concentrating concept with a selective absorber plate significantly increases performance.

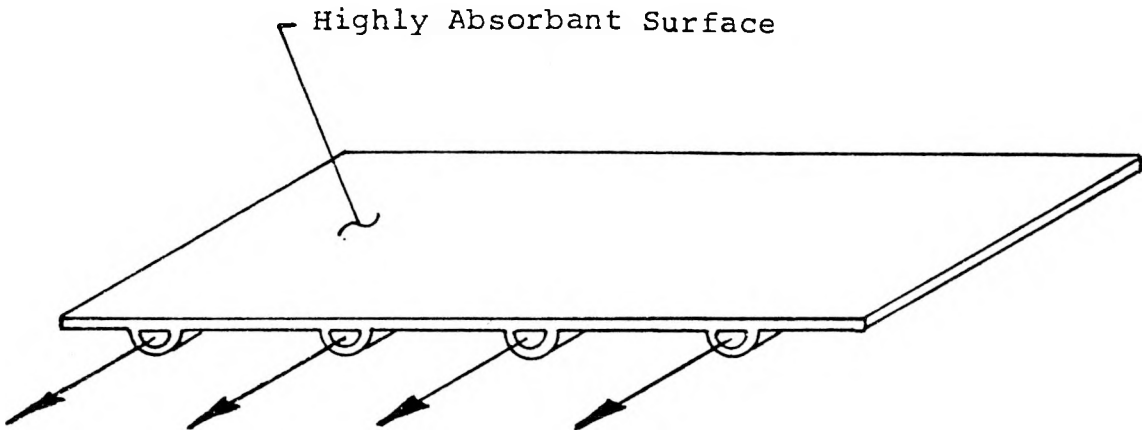


Fig. 1A – Conventional Flat Plate Collector

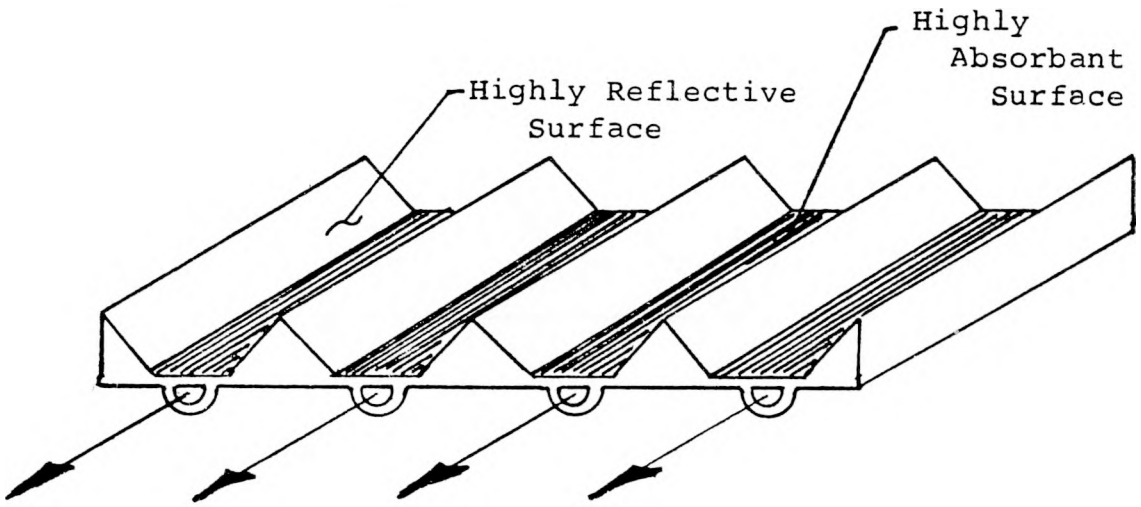
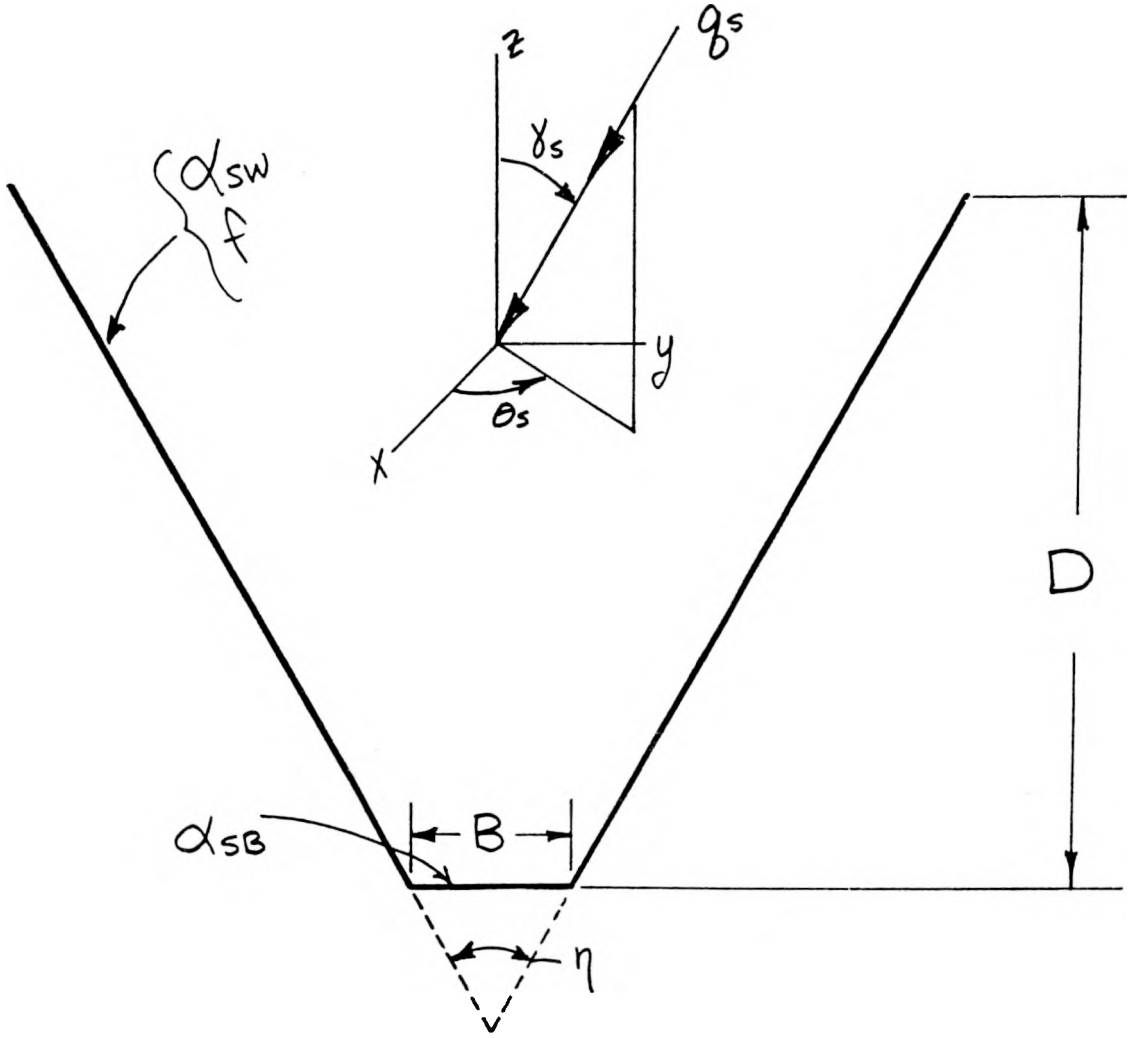


Fig. 1B – Proposed Moderately Concentrating Flat Plate Collector



Variables:

- η, D/B } geometric properties ⇒ fabrication costs
- α_{sB}, α_{sw}, f } radiative properties ⇒ materials cost and reliability
- γ_s, θ_s } latitude, season, time, tilt ⇒ use

Fig. 2 — Simulation Parameters

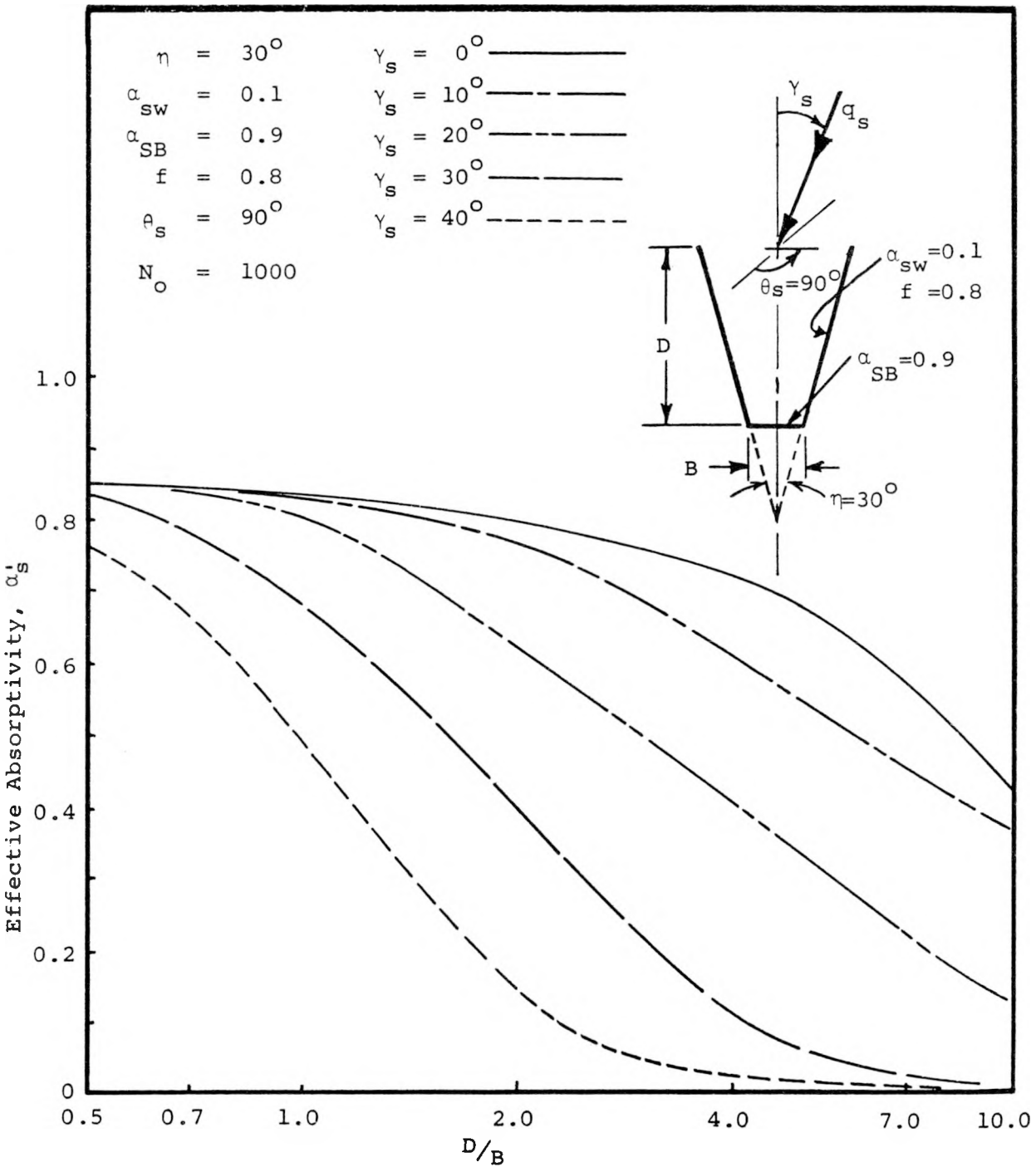


Fig. 3 — Effective Absorptivity as a Function of Groove Depth-to-Base Ratio for Various Sun Angles

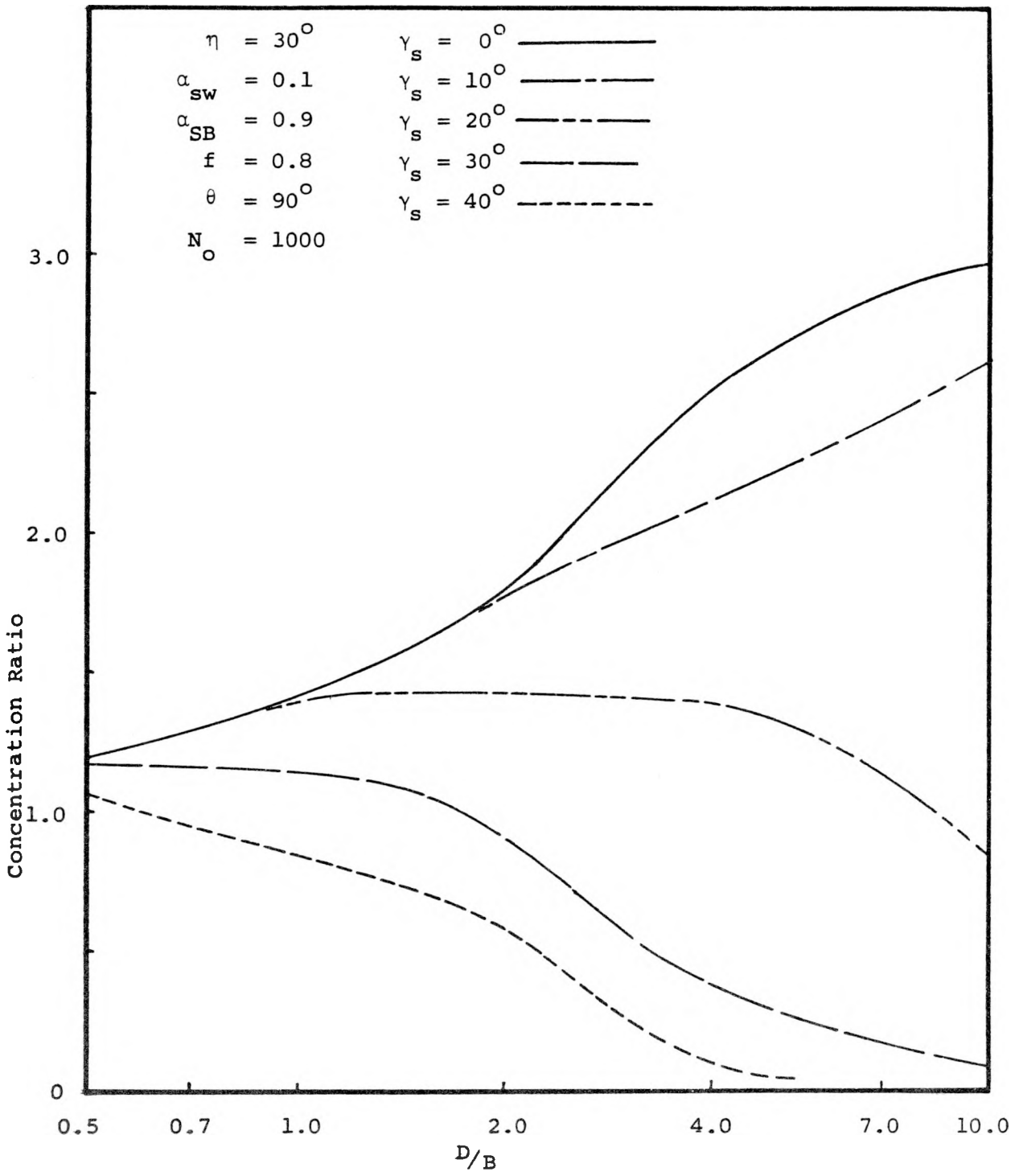


Fig. 4 – Concentration Ratio as a Function of Groove Depth-to-Base Ratio for Various Sun Angles

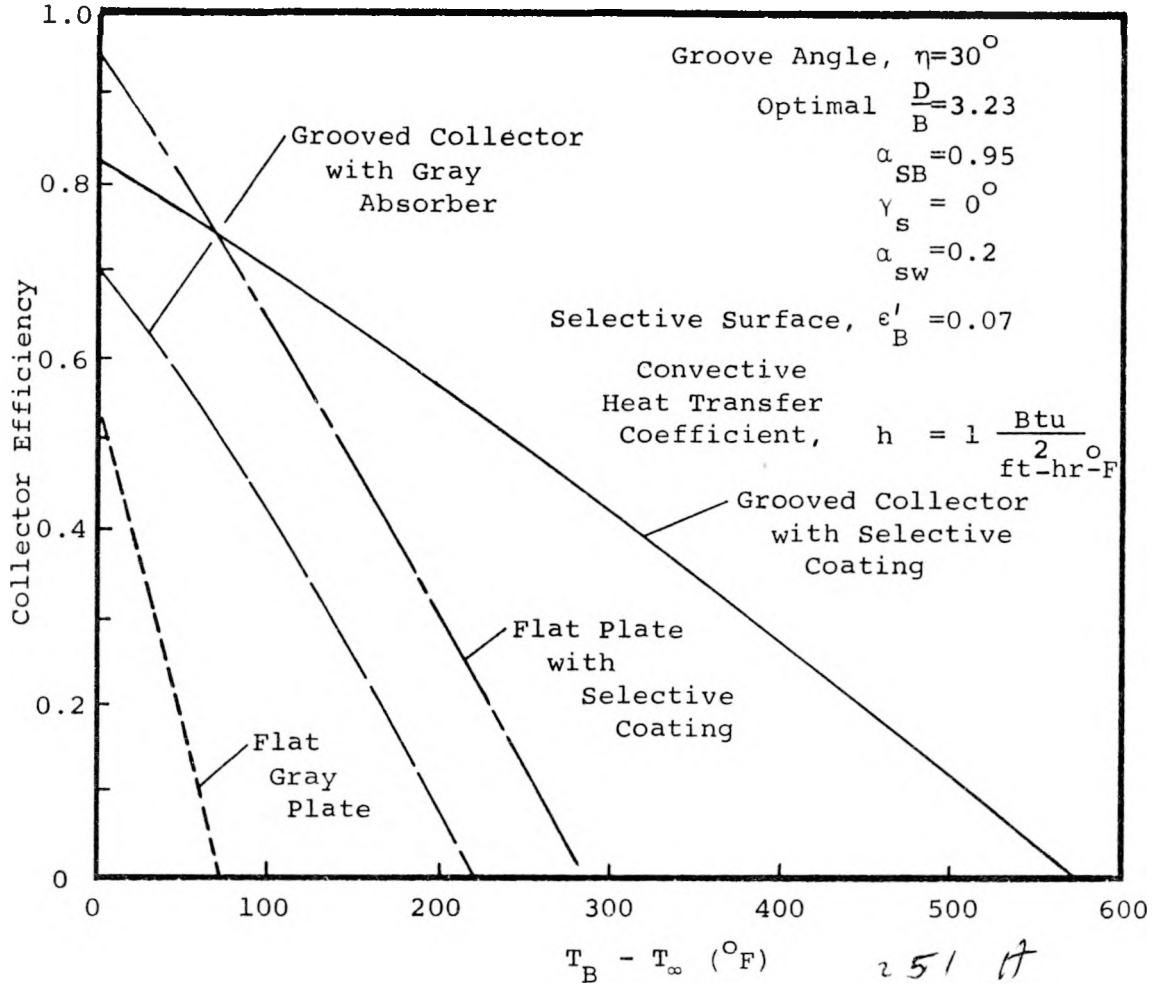


Fig. 5 — Collector Efficiency for Various Collector Configurations

DISCUSSION

Question (William C. Sherbin, Westinghouse Energy Systems): Did you take into account optical losses in the reflector surface? At very high incidence angles to the surface of reflection, the transmission through the glass approaches zero.

Answer (Richard B. Bannerot, University of Houston): The optical properties of the sidewall reflector are characterized as a solar absorptivity and a parameter representing the ratio of specular to diffuse reflections. These are assumed constant (not a function of incident angle) for the present analysis. This effect could be included, however, with only minor changes to the basic Monte Carlo model. The experimental results show the present model to be adequate.

Question (Mr. Sherbin): What is your collector's advantage over the parabolic Argonne model?

Answer: Cost. The two collectors are similar in concept. The main difference is that the Argonne collector requires high-quality, parabolic reflecting surfaces, while our reflecting surfaces are flat and are not necessarily required to be of high quality.

Question (Edward P. Greene, NASA Goddard Space Flight Center): Why did you choose symmetrically sloped mirrors on the north and south facing sides? Wouldn't a steeper sloping mirror on the south side provide better focusing of the ray toward the absorber for the Northern Hemisphere?

Answer: We expect to look at this and other possible configurations.

Question (David A. Boyd, American Science and Engineering): Could we have more details on convective loss calculations; specifically, was convective loss from reflective surfaces considered and was variation of h_c with temperature considered? What portions of the total losses are convective losses?

Answer: The thrust of the current work is radiative transfer analysis. As a result for all calculations shown, h_c was taken as 1 Btu/ft^2-hr-°F (not a function of temperature). For a 200° F difference in absorber plate and ambient temperatures the convective losses were about 90 percent of total losses with the spectrally selective absorber plate, and about 30 percent with a gray absorber plate. Note that convective losses are the same in both cases; it is the large drop in the radiative losses when the selective absorber is used that causes the shift.

Question (Robert F. Boehm, University of Utah): Consider gray surfaces: Can you evaluate effective α/ϵ ratios for your configuration? What might be their values.

Answer: Based on the absorber-plate area the maximum α/ϵ is approximately the concentration ratio times the α/ϵ for the absorber plate. Our concentration can be as high as 10 to 1 for a narrow deep groove. However, such a design would have only a very limited operating period during the day. More realistically a concentration ratio of 3 to 1 should be expected. If the Honeywell selective surface ($\alpha/\epsilon = 13$) is used as the absorber plate, the collector as a whole would have an effective α/ϵ of about 40.

Question (Mr. Boehm): If diffuse input and diffusely reflecting walls are included in your model, how will the collection efficiency change, qualitatively? Also, how will the effective α/ϵ change?

Answer: The diffusely reflecting walls are in the present model. A parameter, which is the ratio of specular to diffuse reflections, is used to help characterize the reflecting wall. It is found that performance (concentration ratio) degrades as reflection diffuseness increases. This effect is not substantial initially (maybe a 5-percent drop in concentration ratio when a 10-percent diffuse wall replaces a truly specular wall). However, the concentration ratio drops to around 50 percent of maximum for a 40-percent diffuse wall. There is a corresponding drop in effective absorptivity (related to collector efficiency) and effective α/ϵ. The diffuse input radiation is currently being added to the program. Intuitively, we expect a degradation in performance, but certainly not as severe as that experienced in focusing collectors.

52/112

NUMERICAL MODELLING OF THERMAL TRAP AND WATER-TRICKLE SOLAR COLLECTORS

By

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Two types of flat plate solar collectors were analyzed numerically and the results compared to experiment. The solar collectors studied were a thermal trap collector and a water-trickle collector.

The analysis of both collectors was on a time dependent basis and considered the thermal inertia of the water storage tank which the collectors supplied. The incident solar radiation and the ambient atmospheric temperature were taken to be known functions of time. The mathematical model of the collectors considered that the main heat transfer took place in a direction normal to the flat collector plate. Hence, for each element of a collector, e.g., the glass cover plate, the time dependent, one-dimensional partial differential equation, which is a statement of the conservation of energy for that element, has to be solved. Since each collector contained several elements, the simultaneous solution of several non-linear partial differential equations was entailed. The boundary conditions on the partial differential equations were that the conduction heat transfer at the boundaries equal the sum of the convective and radiative heat transfer. The numerical procedure used in the solution of the simultaneous partial differential equation was an explicit or marching technique. Calculations were carried out and the results plotted on the New Mexico State University IBM 360/65 digital computer.

Collector Test Station. The thermal trap flat plate solar collector is 2 feet by 4 feet in collecting area. The collector plate is of Roll-Bond aluminum with an 8-loop serpentine water passage. The back insulation consists of 3-inch polyurethane and the side insulation of 2-inch polyurethane. The thermal trap material is a 2-inch slab of methalmethacrylate atop the Roll-Bond collector plate. The water-trickle solar collector uses a corrugated aluminum collector plate 4 feet by 4 feet in collecting area. Water trickles from a manifold at the top of the collector down the troughs in the corrugated aluminum. A single sheet of plate glass covers the collector. The collector plates of both solar collectors are painted flat black using 3-M black velvet paint.

The solar collectors supply a single 200-gallon water tank which is insulated with 6 inches of vermiculite. Each collector has its own flow meter and thermocouples for continuously recording water flow rate and various temperatures including, water inlet and outlet temperature, collector plate temperature, etc. The temperature of the water in the storage tank is also continuously recorded along with solar intensity and ambient temperature. Water is pumped from the storage tank through the collectors by a single pump which is automatically turned on each day by a timer.

The numerical models of the collectors were checked by comparing the day long performance of the actual collectors to their numerically predicted performance. The results of this comparison, as shown in Figures 1 through 3, proved that the numerical model of the thermal trap flat plate collector accurately predicted its overall performance. However, the numerical model of the thermal trap collector did not appear to have quite as much thermal inertia as the actual collector. The shapes of the calculated temperature-time curves were similar to the measured curves and the calculated total amount of

energy collected was identical to the measured total. The failure of the numerical model to accurately predict actual thermal inertia effects is probably due to the two-dimensional effects, i.e., the model is one-dimensional and the test collector is small, hence edge effects are probably not negligible.

The numerical model of the water-trickle collector did not accurately predict the performance of the test collector. However, the shapes of the calculated temperature-time curves were similar to the measured curves, as can be seen in Figures 4 through 6. The difference between numerical results and measured results appears to be attributable to the uncertainty of the amount of solar flux which gets through the cover plate of the collector after water begins to condense on the inside of the cover.

In conclusion, a one-dimensional numerical model of a thermal trap flat plate solar collector is adequate to determine the overall performance of this type of collector. However, it appears that for the thermal trap solar collector, a two-dimensional numerical model may be required to obtain a satisfactory representation of the thermal inertia effects. The water-trickle solar collector can not be modelled unless the attenuation of the incoming solar radiation due to water condensed on the interior of the glass cover plate is properly taken into account.

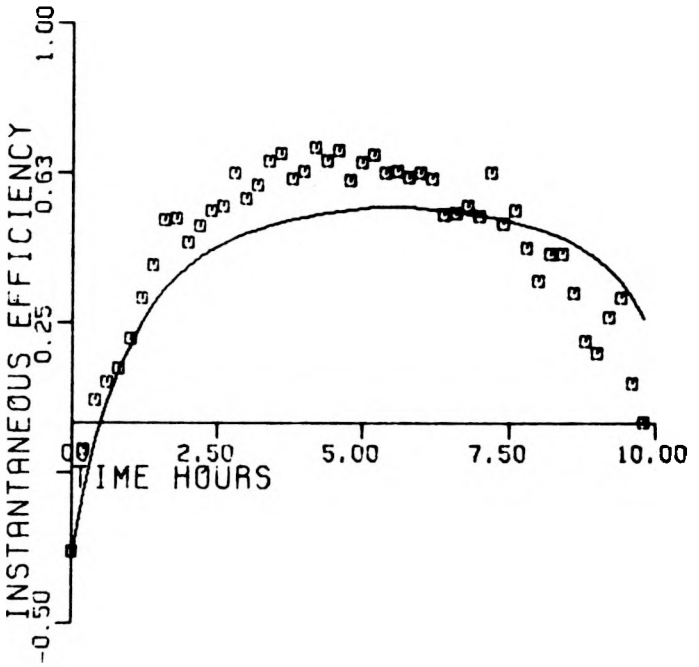


Fig. 1 — Instantaneous Efficiency of the Thermal Trap Collector
(— Theory, ⊡ Experiment)

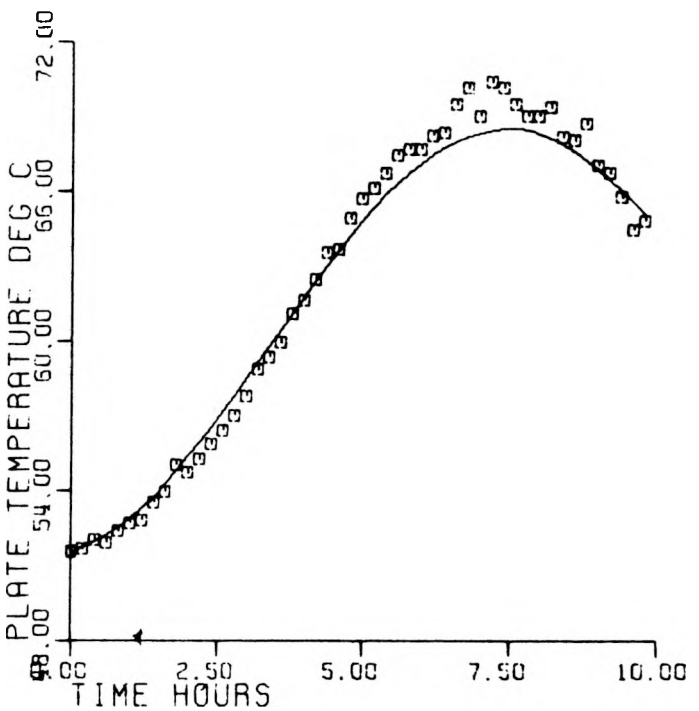


Fig. 2 — Plate Temperature of the Thermal Trap Collector
(— Theory, ⊡ Experiment)

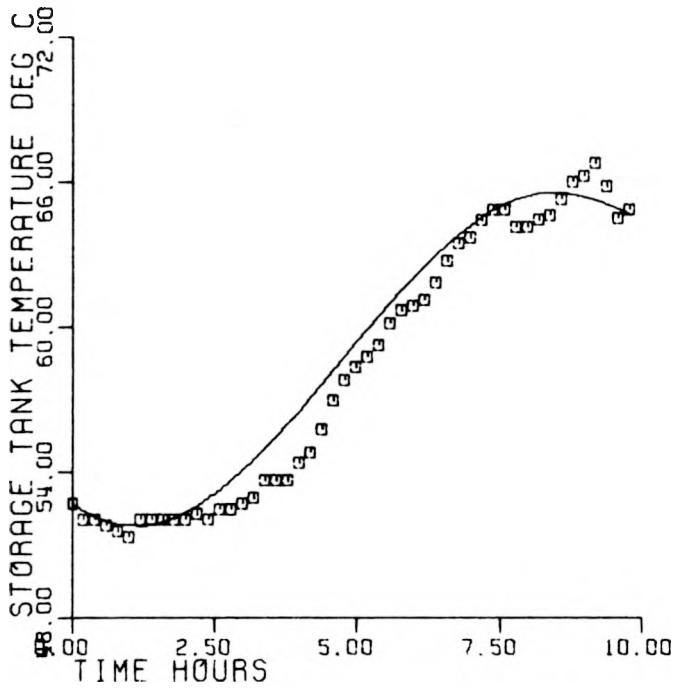


Fig. 3 — Temperature of the Water in the Storage Tank of the Thermal Trap Collector (— Theory, ⊡ Experiment)

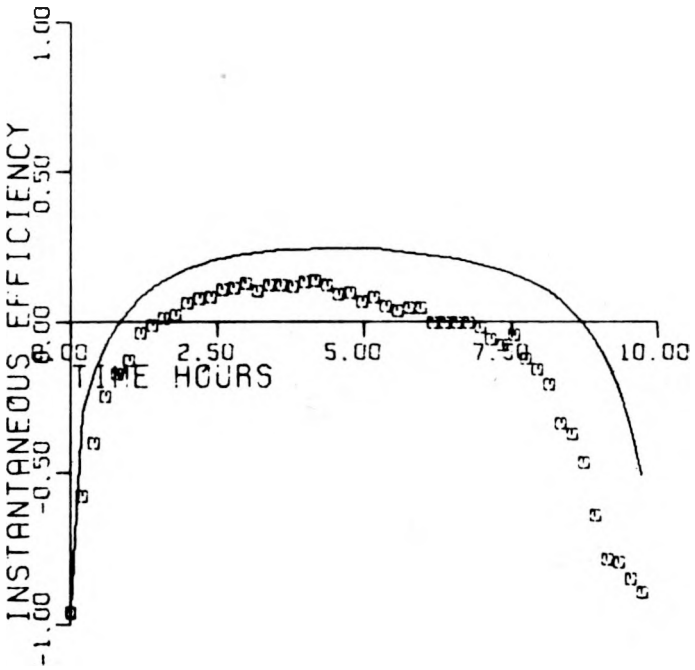


Fig. 4 — Instantaneous Efficiency of the Water-Trickle Collector (— Theory, ⊡ Experiment)

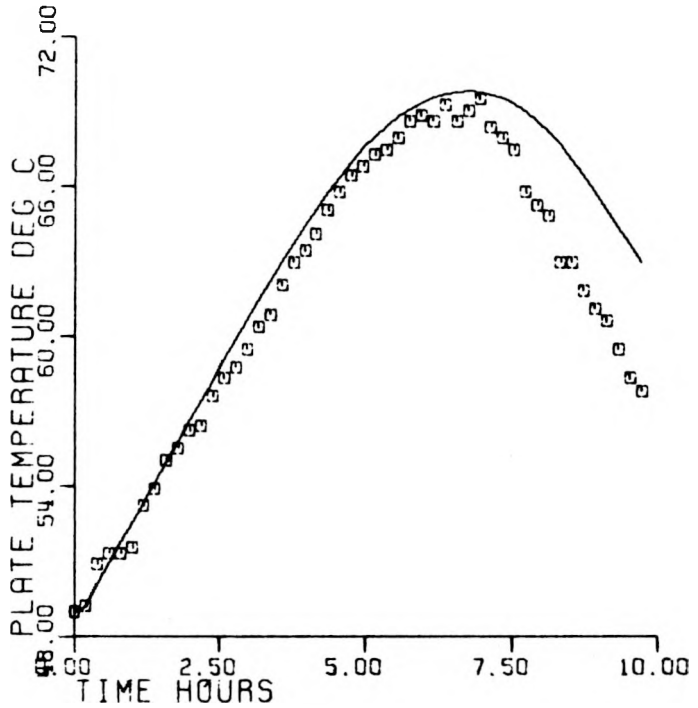


Fig. 5 — Plate Temperature of the Water-Trickle Collector
(— Theory, ⊡ Experiment)

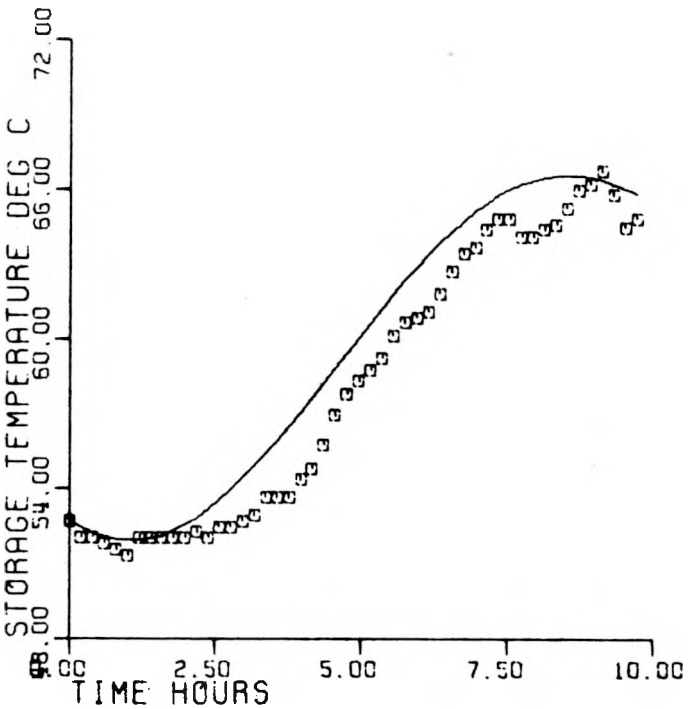


Fig. 6 — Temperature of the Water in the Storage Tank of the
Water-Trickle Collector (— Theory, ⊡ Experiment)

DISCUSSION

Question (K. G. T. Hollands, University of Waterloo): Do you assume that all of the solar energy is absorbed on the black plate of the thermal trap, or do you allow for the absorption of some of the near infrared solar in the methylmethacrylate sheet?

Answer (Philip R. Smith, New Mexico State University): Yes, some of the solar energy is absorbed in the methylmethacrylate sheet before striking the collector plate. This is taken into account in the numerical model.

Question (Carleton Granbery, Architect): What was the rate of flow of liquid used in the trickle collector model and how was it controlled? How many gallons per hour per square foot of collector?

Answer: Rate of flow for the trickle collector was 0.2 gal/min or 0.75 gal/hr-ft^2.

Question (Andrew E. Scoville, The Stanley Works): What are the characteristics of the methylmethacrylate layer used in your collector model?

Answer: Properties of methylmethacrylate:

Thickness, 2 inches
Thermal conductivity, $k = 0.1$ Btu/hr-°R
Thermal diffusivity, $\alpha = 0.00381$ ft^2/hr
Specific gravity, S.G. = 0.96
Transparent to about 1.7 microns, opaque to all higher wavelengths

Question (Robert C. Liu, U.S. Department of Agriculture): What solar collector system (thermal trap or water trickle) will be used for the new agricultural building at New Mexico State University? Is the building for office space or for other services?

Answer: Double-glazed, flat plate collectors will be used on the NMSU State Agriculture Building. The building has both offices and laboratories.

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THE HOTTEL, WHILLIER, BLISS COLLECTOR MODEL

W.A. Beckman
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Madison, Wisconsin

The first detailed analysis of a flat plate solar collector was presented by Hottel and Woertz[1] in 1942. This classic paper laid the foundation for all subsequent collector analysis. In 1958 Hottel and Whillier[2] extended the original work to include, in a more fundamental manner, the effects of temperature gradients in the flow direction. In 1959 Bliss[3] presented collector efficiency factors for several collectors not considered by Hottel and Whillier. The text, Solar Energy Thermal Processes[4], discusses these developments in detail. The result of these analysis is the following equation for the useful energy gain of a collector:

$$Q_{USEFUL} = A_C F_R [S - U_L (T_{INLET} - T_{AMBIENT})]$$

where A_C is the collector area

F_R is the collector heat removal factor

S is the solar energy absorbed by the plate

U_L is the collector overall loss coefficient

T_{INLET} is the inlet fluid temperatures and

$T_{AMBIENT}$ is the outside ambient temperature.

This particular form is very convenient when analyzing solar energy systems since the useful energy gain is found from the inlet fluid temperature which is usually known. The quality in the square brackets represent the difference between the energy absorbed by the plate and the energy lost by the collector if the whole collector had been at the inlet fluid temperature. It is obvious that losses do not occur from the inlet fluid temperatures but from some average plate temperature which is higher then the inlet fluid temperature. The effect of the multiplier F_R is to reduce the useful energy gain from what it would have been if the whole collector had been at the inlet fluid temperature to what it actually is with a fluid that increases in temperatures as it flows through the collector.

A typical plate and tube heat exchanger is illustrated on Figure 1a. The temperature distribution of the plate is illustrated in Figure 1b. At a fixed value of Y, the temperature distribution between the two tubes is as shown in Figure 1c. At a fixed value of X, the temperature increases in the Y direction from a value at the inlet to some higher value at the outlet end of the collector as shown on Figure 1d. All of these temperatures gradients are taken into account by the heat removal factor, F_R. When a complete analysis is made of a fin and tube solar collector, the heat removal factor is found to be independent of the absorbed solar energy, but is a function of the mass flow rate per unit area, G, the specific heat of the flowing fluid, C_p, the collector loss coefficient, U_L, and the collector efficiency factor, F'. For any given collector design, the collector efficiency factor F' is essentially a constant. The evaluation of F' will be more fully described below. As seen in Figure 2 the quantity F_R can never exceed F' since the ratio F_R/F' is limited to the range from 0 to 1. The ratio F_R/F' is given the symbol F" and is called the collector flow factor and is a function of a single variable GC_p/U_LF'.

The evaluation of the overall loss coefficiency U_L requires knowledge of the radiation and convention heat transfer between two parallel plates. Radiation heat transfer between parallel plates is not a difficult calculation. The evaluation of convection between two parallel plates requires experimental data on the influence of plate temperature difference, plate spacing and fluid properties on the overall heat transfer coefficient. In 1958 Tabor[5] evaluated the existing literature and proposed a heat transfer correlation between the Nusselt number and the Grashof numbers for two parallel flat plates oriented vertically, horizontally and at 45°. Using this information, top loss coefficient have been evaluated for flat plate collectors under a variety of operating conditions. Figure 3 is an example of the type of results that have been obtained using Tabor's correlation. In this figure the collector slope is 45°, the wind speed is 5 meters per second and the plate long wavelength emittance is 0.95. The graph covers the range of plate temperatures from 10°C to 130°C with ambient temperatures of 40, 10 and -20°C. The three sets of curves represent 1, 2 and 3 glass covers. Recently, Klein[6], developed an empirical equation giving the top loss coefficient as a function of average plate temperature, wind speed, plate emittance, number of glass covers and angle of tilt.

As indicated in Figure 1c a temperature gradient exists in the sheet between the two tubes. Because the region between the tubes is at a higher temperature then the region above the tube, the losses from the central regions are correspondingly higher. In order to account for this effect, a standard fin

efficiency can be defined which relates the performance of the actual plate to the performance of an idea plate. That is, a plate with an infinite thermal conductivity. This fin efficiency is shown on Figure 4 as a function of the tube spacing W, the loss coefficient, U_L, the tube diameter, D, and the product of the plate thermal conductivity and the plate thickness, $k\delta$.

The collector efficiency factor, F', is defined as the ratio of the useful energy gain to the useful energy gain if the collector absorbing surface were at the local fluid temperature. For a fin and tube collector with a good bond conductance, F' can be expressed as:

$$F' = \frac{1/U_L}{W\left[\frac{1}{U_L[D+(W-D)F]} + \frac{1}{\pi D h_{f,i}}\right]}$$

The quantities W, D and U_L are as shown on Figure 4. The quantity $h_{f,i}$ is the heat transfer coefficient inside the tube. The collector efficiency factor is plotted on Figure 5 for a value of U_L equal to 4 W/m^2C and $h_{f,i}$ equal to 300 W/m^2C as a function of the tube spacing with the product of the plate thermal conductivity times plate thickness as the parameter. This graph corresponds approximately to a two cover collector with natural circulation of the fluid. Collector efficiency factors have been evaluated for a large number of collector geometrics and are summarized in reference 4.

With F' known, it is a simple process to obtain a numerical value for F_R. With knowledge of the instantaneous incident solar radiation, the transmittance of the glass and the absorptance of the plate, the overall loss coefficient and the collector heat removal factor, it is possible to predict the collector useful energy gain.

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3. Bliss, R.W., Solar Energy, 3, 55, No. 4 (1959). "The Derivations of Several 'Plate Efficiency Factors' Useful in the Design of Flat-Plate Solar-Heat Collectors."

4. Duffie, J.A. and Beckman, W.A., Solar Energy Thermal Processes, John Wiley and Sons, (1974).

5. Tabor, H., Bull. Res. Coun. Israel, 6C, 155 (1958). "Radiation Convection and Conduction Coefficients in Solar Collectors."

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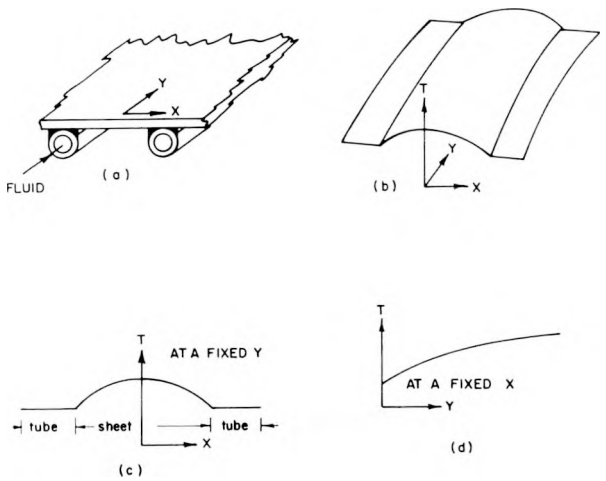


Fig. 1 — Typical Flat Plate Collector Temperature Distribution

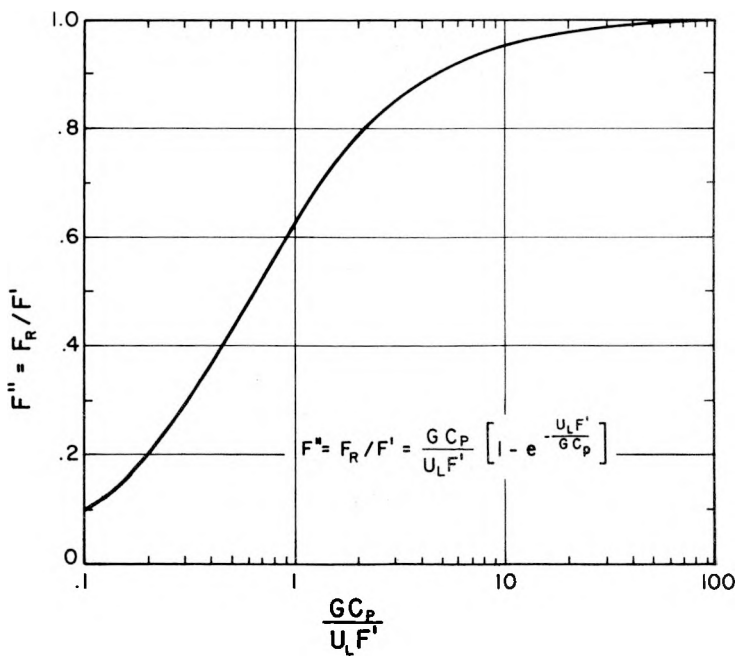


Fig. 2 — Collector Flow Factor

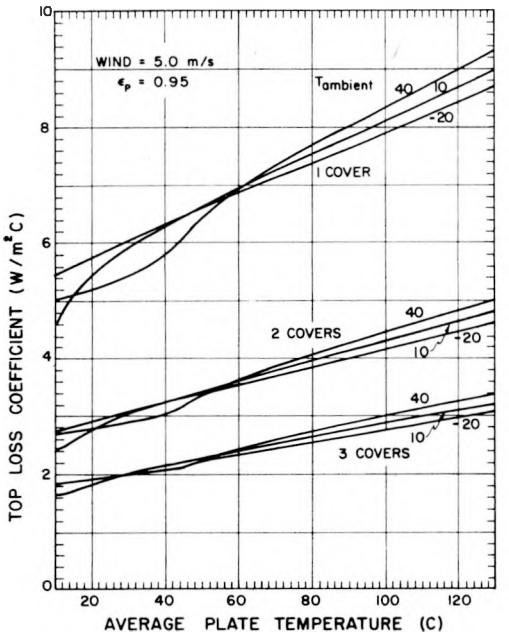


Fig. 3 — Typical Collector Top Loss Coefficients (45° tilt)

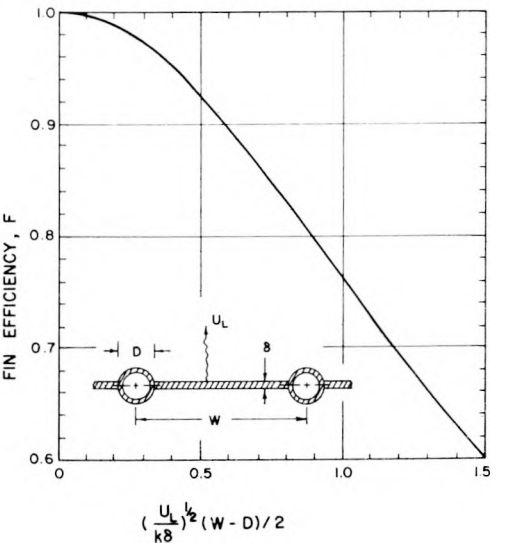


Fig. 4 — Collector Fin Efficiency

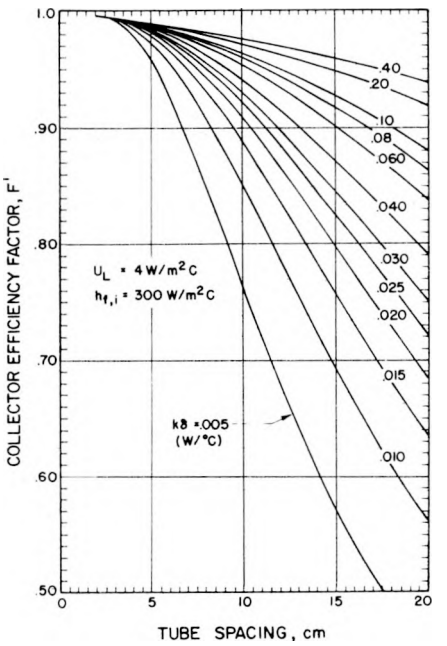


Fig. 5 — Collector Efficiency Factor for Plate and Tube Collector

DISCUSSION

Question (John R. Biddle, California State Polytechnic University): Does your model include diffuse radiation? If so, how was it incorporated? If not, why was it not incorporated?

Answer: The diffuse radiation is included in the quantity *S*. *S* is defined as the solar energy absorbed by the plate and is made of the beam and diffuse components of radiation that pass through the glass cover and are absorbed by the plate. If the division of beam and diffuse radiation is known, it is not a difficult task to evaluate the absorbed beam radiation, but the diffuse radiation is a somewhat more complicated problem. If the spatial distribution of diffuse radiation is known, then a relatively straightforward integration can be performed to determine how much of this diffuse radiation actually passes through the cover system and is absorbed by the plate. The distribution of diffuse radiation is usually not known, so that it is necessary to make an assumption. Basically three kinds of assumptions have been used. The first is that the diffuse radiation is uniformly distributed over the collector hemisphere. The transmission of a glass cover system for diffuse radiation is then approximately equal to that for beam radiation at an angle of incidence of 60°. The second assumption is that the diffuse radiation is uniform from the sky and also uniform from the ground, but of a different magnitude. This assumption leads to a relatively simple formulation for the incident diffuse radiation, but the calculation of the cover transmission requires an integration to determine an effective angle. The third assumption is that all diffuse radiation comes from the vicinity of the sun. This assumption certainly is reasonable under high solar radiation conditions, i.e., under conditions in which most of the useful energy gain of the collector will be realized. It is certainly a poor assumption on a totally overcast day, but on such days the amount of useful energy gain is usually very small. I am sure that there are exceptions to this rule, particularly in a climate like Miami that has a significant amount of diffuse radiation.

Question (David Lee, A.D. Little, Inc.): From your experience with simulation, how important are transient effects?

Answer: In a recent study by Klein et al. ("Transient Considerations of Flat Plate Collectors," *Trans. ASME: J. Engr. Power*, 96A, 109, 1974), the transient effects were shown to be negligible for collectors of a more or less conventional design. We have found that if collector heat capacity effects are important, it is possible to use a so-called one-lump model for these effects. This one-lump model is described in detail in the text *Solar Energy Thermal Processes.*

Question (Herman G. Barkmann, Barkmann Engineering): What gain system optimization can be realized by use of actual insolation data over generalized interpolated data.

Answer: I assume here that the question refers to interpolating data from station to station. This is an extremely risky business and should be avoided if at all possible. Local weather conditions can seriously alter the radiation in certain locations from what you might expect by interpolating between measuring stations. I can only hope that in the future we will have better radiation data to work with so that we do not have to contend with this problem for large population centers.

LUNCHEON ADDRESS

by

Congressman Mike McCormack
4th District, State of Washington
Chairman, Subcommittee on Energy of the
House Science and Astronautics Committee

The Workshop Luncheon was held on Friday, November 22, in the Mercury Ballroom of the New York Hilton Hotel. Head table guests were:

Redfield Allen, Professor of Mechanical Engineering, University of Maryland
Donald Beattie, Director, Division of Advanced Energy Research and Technology, NSF/RANN
Lloyd Herwig, Director, Advanced Solar Energy Research and Technology, NSF/RANN
Hoyt Hottel, Professor Emeritus of Chemical Engineering, Massachusetts Institute of Technology
Congressman McCormack
Dudley Ott, Vice President for the Power Department, American Society of Mechanical Engineers
Richard Robertson, President, American Society of Mechanical Engineers
Mrs. Richard Robertson

Mr. Beattie served as master of ceremonies. Brief remarks were delivered by Mr. Beattie, Mr. Robertson, Mr. Ott, and Professor Hottel, after which Mr. Robertson introduced Congressman McCormack.

LUNCHEON ADDRESS ON FRIDAY, NOVEMBER 22

Congressman Mike McCormack
4th District, State of Washington

I want, first of all, to say a word of congratulations to ASME for its work, not only in energy, not only for their support in so many ways of those of us in Congress who are trying to work on energy-related problems, and not only for the recent publication, The U.S. Energy Prospectus and Engineering Viewpoint, which they have just completed, but I also want to congratulate ASME for its Congressional Fellowships.

You know, Dick mentioned in his introduction that I am one of two scientists in Congress. I am not particularly proud of this fact. I think that is a sad commentary on our society that our political system and our industrial hierarchy is such, and our university hierarchy is such, that it is almost impossible for a person with a technical or scientific background to become active enough in politics to work his way into a seat in Congress.

It is a bad situation. One of the things that I tried to do to help overcome that, as soon as I became a member of Congress, was to try to collect at least a qualified technical staff around me on the Science and Astronautics Committee.

One of the ideas we soon came up with, in conjunction with ASME, was the idea of Congressional Fellowships, and we have had a number of them. ASME has led the way in this particular project, and it has been supported by AAAS, the American Physical society,the IEEE, and a couple of the other professional societies, but ASME has led the way, and I am very proud of it.

We have had Bill Miller and Barry Hyman, whom some of you know, and now we have Dr. Jim Cox and Bert Nelson working on the Hill as ASME Fellows. They are extremely valuable, and this is a real contribution to the government, helping Members of Congress who don't have a technical background to at least get some idea of the facts of the subject before them.

With every passing day the problems facing this government are more technical, more scientific, less political, less a matter of opinion, more a matter of fact. We need men there who can help interpret these questions, help Members of Congress who must make the decisions, understand them.

So I want to congratulate you. I also want to congratulate NSF for the work that it has been doing in this particular area. You know, Don was mentioning that in the Spring of 1973 when NSF set up its solar conference in Washington, D.C., I came and spoke to that meeting, too.

I was thinking about it as I came up on the airplane, and I guess we agreed there were about 80 persons there altogether, and that is a pretty good change in about a year and a half. And a lot of this has been due to the leadership of people like Lloyd Herwig and Don and others in the National Science Foundation.

So I want to congratulate you. At that meeting a year and a half ago, I talked about getting to work. Perhaps some of you remember I commented on the need for enthusiasm and dedication and getting out and doing a job, not just sitting there and talking about it. Some of us in Congress at that time, and some of the members on my staff, people like Tom Ratchford and John Andelin, whom some of you know, and Kirk Hall, had faith that with some support from Congress solar energy could start to move.

I think this meeting today, and your attendance, and the material that has been presented here today, demonstrates that we were right. We were right because we did have and do have faith in you. I don't say that patronizingly in any way, but you are the ones who have to make this thing work; the scientists and engineers in research and development, in companies, in national laboratories and universities, in professional societies, and those of you who are individual entrepeneurs.

This coming together and sharing ideas and hashing them out and, yes, getting some criticism like Hoyt Hottel presented is a good thing, and I hope it does continue. Now, of course, we are looking to all of you to confirm our faith in the future of solar energy. Solar energy will become a viable and competitive source of energy, first for the heating of buildings, and then for the heating and cooling of buildings, and still later for the generation of electricity and production of synthetic fuels.

So it is a good feeling to be here with you today and to see the enthusiasm. I understand you were up until about 11 o'clock last night, and that kind of enthusiasm is the sort of thing that will make it all go.

Now I have some good news for those of you who are particularly interested in solar heating of buildings or heating and cooling of buildings. And that is that under the Solar Heating and Cooling Demonstration Act we are proceeding. The day before yesterday, the National Bureau of Standards released its first preliminary draft of performance criteria for solar heating and cooling devices, and for buildings in which they will be installed.

I talked yesterday to Jack Harrison Schmitt at NASA. I understand you will be having a briefing today from representatives of NASA and HUD. The work that NASA and HUD are doing in the plans for procurement strategy and involvement of individual entrepreneurs is on schedule and under way, and will have a release by Christmas, which will be on schedule, of this material in preparation for implementing the Solar Heating and Cooling Demonstration Law.

I am very happy with that. Now, there are going to be some awkward moments and some awkward pauses during the months to come at the federal government level as we phase into ERDA, because ERDA is taking over the heating and cooling business. But we have, first of all, the NSF present

lead agency occupation in this area, and then at the same time we have the Heating and Cooling Demonstration Law which, under the Energy Reorganization Act, moves over into ERDA but doesn't do so at any designated time.

We are going to try to delay that as long as we can, to try to have the heating and cooling program uncomplicated by the problems of creating ERDA, all the administrative problems that will be involved in converting an AEC to an ERDA and hope we can move this program forward as fast as we can. But there will be some moments of frustration.

I want you to know that we will be working with NSF and with you and with NASA and HUD and with the Office of Management and Budget to try to do everything we can to smooth those out to keep this program going. If there is any time when you feel a bit frustrated because the bureaucracy seems to have things all fouled up, just remember that is a normal situation. Don't let it bother you. Just keep going. Sooner or later it will work out.

Unfortunately, solar energy isn't going to solve all of this nation's immediate or even intermediate range energy problems. This is really what I would like to talk to you about today.

You have a whole roomful of experts here on the subject of this conference, and far be it from me to try to talk to you about specific details of this subject today. I would rather like to enlist your help on what I think is a mission of great importance to our nation, and that is really a matter of understanding a little better what the energy crisis is and how it really impacts upon us, and what is our responsibility with respect to it. That is particularly true for those of you here in this room, not only because you are scientists and engineers, but also because of the fact that you are all experts in solar energy. This gives you a particular advantage that I think we need to exploit.

You know, the shortages of petroleum products experienced by Americans a year ago accomplished what 20 years of warnings by scientists couldn't do. It made most Americans aware of the fact that this nation can no longer control the energy supplies of weaker nations to our advantage and to their disadvantage, and force them to deliver their resources to us. It has made American aware of how much we depend upon a prodigious consumption of energy for our standard of living. It is making Americans aware of the importance of the impact of the importation of expensive petroleum, how it affects our economy, and how these prices influence the inflationary pressures that we are now experiencing in this country.

Unfortunately, our society is not ready yet to face up to all the implications of all these new realities. What may not be yet apparent to the casual observer is that the total energy consumption of our nation must continue to increase, even if we establish successful conservation programs. We are faced with really a frightening spectrum of implications associated with such an increase in total energy consumption, on the one hand, and the conservation programs we we must institute on the other, to say nothing of all the inflationary and economic problems.

Now, a concerned citizen would obviously listen to some of these problems and say, well, what are we going to do? At least, any problem solver would say, what are we going to do, which I suppose, put into Washington, D.C., jargon would read, well, what is our energy policy?

The answer is, of course, that we do not have an energy policy at all. This national never has had an energy policy and doesn't have one today. There is an attempt now to develop an energy policy, but throughout all of our lives, the general public and the government have assumed that all energy sources were too cheap to be worthy of consideration, inexhaustible, and, until recently, even non-polluting.

The challenge that we face today is to overcome this confusion and indifference and develop a new systems approach to an integrated energy policy. If we do create such an energy policy, and if we implement the programs to carry it into effect, then the people of this country can have both the adequate energy, and the environmental protection that we all want.

But if we fail, the inevitable result--and I say this sincerely--will be national catastrophe. In the first place, we must have a systems approach for integrated national energy policy. I will come back to this time after time. This is an essential requirement if we really intend to overcome the energy crisis.

We must include, along with the administration of all energy research and development and demonstration, an assessment and management of all fuels, an understanding of the supply and demand for each type of energy and fuel for each region of the country, and the economic impact and environmental feasibility of any energy-related proposal.

It is essential that we establish, within the executive branch, a single administrative agency with the authority to implement such a policy. We do not have that today. The fundamental, essential criterion to solv- our energy problems, is to have an agency within the executive branch with the responsiblity and the authority to implement and carry our a national energy policy. Obviously a national energy policy isn't some sort of fixed dogma, but there are some guidelines I think we can talk about, consider, and live with right away.

First of all, it must be based on the best information available, on the truths as they become apparent. We can't afford the luxury of basing policies on fantasies, and one of the fantasies I want to talk about particularly to this group is the one that keeps popping up over and over again: that solar energy or geo-thermal energy or some suppressed carburator design will bail us out of our immediate energy problems.

We can't base our policies on prejudices, such as on anti-nuclear fanaticism, or on hope, such as the hope that we will keep finding enough natural gas to keep going, or the hope that the people of this country will somehow spontaneously reduce their energy consumption and alter their lifestyles enough to close the gap between supply and demand and make us independent.

These things are not going to happen. Obviously a national energy policy must provide the optimum conservation practices through every step of everything we do, and in particular respect to the conversion and transmission and consumption of energy. For instance, just as it is obvious we shouldn't be burning natural gas today to general electricity, so in the very long run we should not be burning any fossil fuels at all.

A national energy policy must allow for a higher standard of living for most people in this country. This ability to gain a higher standard of living is fundamental in our society, and we must design a national energy policy that will permit it. The challenge in accomplishing this goal is our ability to provide the leadership in developing new cultural patterns which will recognize that a truly higher quality of life is possible with a lower per capita comsumption of energy than is assumed necessary today. This will not be easy, particularly in view of the fact that the traditional measure of the standard of living in any society is generally considered to be a direct function of energy consumption.

A national energy policy should, I believe, provide for energy self-sufficiency for this nation, not by 1980 or 1985. This is pure political rhetoric; nothing else. But as soon as possible, and certainly by the year 2000.

Still further, and of great importance, we should plan now and announce now that we will export the technology that we shall develop to every nation on this earth, so that no nation will be dependent on any other nation for its energy or subject to blackmail for its survival.

This is one of the most important contributions this country can make to the world in terms of reducing international tensions and to bring true and lasting peace. Now of course, it will never be completely successful, but nevertheless it is a goal for which we can strive.

Finally, our national energy policy should provide for an ultimate reliance upon inexhaustible supplies of essentially non-polluting sources of energy. Of course, this means solar energy and nuclear fusion.

One of the great disservices that has been committed during the recent months in this country by some spokesmen is the publication of statements to the effect that the energy crisis is over. Nothing could be further from the truth, and nothing can do greater harm to this country than to have the general public assume that the energy crisis is limited to waiting in lines for gasoline.

One of the most important facts that we must all understand is that this nation has since 1970 truly passed from one historical era into another. We have passed from an era of cheap, abundant energy and materials into a era of shortages of fuels and energy and materials which will last at best for many decades. The implications of this transition are far more profound than is generally appreciated.

I think it may have a salutary effect upon our perspective to recognize that future historians will probably record that during the 20th

century, Western man discovered and burned up virtually all the earth's resources of petroleum and natural gas.

A graph of this period written in the future will just show one blip for the 20th century when all this material was discovered and consumed. This may be a difficult reality to face. We must assume that this nation has already consumed more than half of all the petroleum and natural gas that has ever been discovered or that we ever will discover on this continent or on its shores. And it will all be gone, insofar as a significant supply of fuel is concerned, by the year 2000.

I made that statement recently, and somebody said, "Oh, that's not necessarily true. What if we discover another Prudhoe Bay?" Well, consider the Prudhoe Bay resource. The fact is that, supplying our total energy consumption, it would last us for 14 months. This is the significance that we must understand.

As our supplies of petroleum and natural gas dwindle toward the end of this century, this nation will become dependent for almost all of its energy on coal and coal products and on nuclear fission. But even these sources of energy are transitional, and we must make them really transitional. As we phase them in, we must also make plan for phasing them out in the more distant future and replacing them with other, still to be developed, sources, such as solar energy, nuclear fusion, if it works, and geo-thermal energy.

Thus we have one generation within which to develop these new sources of energy. And while we are making this conversion, we must make the necessary cultural, societal, and economic adjustments that will inevitably develop.

One of those, by the way, is going to be a series of very serious conservation programs. One that has to come is in the area of transportation. This is going to be one of the most difficult things that we have to face. This romance that we have with the automobile is an emotional block that is going to be extremely difficult to overcome. I just came out of an election campaign where I shook thousands of hands at factory gates and mill gates and places like that. Quite frankly, I am afraid that there are all too many people who would sooner give up their civil rights than their automobiles. I think that this is going to be a tough thing to do: to carry the message that we are simply running out of fuel.

This is not a matter of choice. We must understand that we must undertake these programs. One general misconception plaguing policy makers today is the idea that energy reserach and development, generously funded, can solve this nation's energy problems in the very near future. Nothing could be further from the truth, and you as professionals know this, and so do I. But all too many policy makers and newsmen don't know it, and they are the ones that we must reach.

Even with a crash program, for instance, the lead time between the successful research program, demonstrating its concepts for the conversion of an energy source to a usable form, and the actual significant implementation of this technology varies from 10 to 30 years, and it's usually on a longer run. There is no way, for instance, that a tidal wave of federal funds could make solar energy a significant resource for this nation before the year 1990, or nuclear fusion before the year 2000.

While we must develop an aggressive, imaginative, well-funded program of energy research, development, and demonstration, we must at the same time recognize that the benefits of such a program are long-range benefits. This nation must proceed for the immediate and short-range future with energy sources that are available to us today.

It is therefore in order for us to look at what we must do today to provide for this nation's short-range energy needs. In the first place, we can and we must be prepared to conserve enough energy to provide for essential needs and any contingency, and this means another blockade of Middle East oil, by the way. We must also, of course, initiate comprehensive conservation programs in everything we do. To do this we must seriously consider a new life style. We must at once initiate aggressive programs of exploration and drilling for oil and gas onshore and off, wherever it can be found.

We must explore the potential for an oil shale program and assist, as is mutually advantageous to both nations, the development of Canadian tar sands. We must develop new refineries, new ports, new pipelines, new storage facilities for gas and petroleum and petroleum products. This is our best short-range strategy for trying to keep the energy supplies for our existing industrial and societal infrastructure as close as possible to meeting our short-range demands.

Of course, coal is our greatest resource of fossil fuel, and we must rely heavily upon it. But even a superficial glance should warn us against taking it for granted. I guess the strike today emphasizes that, but that is only the easiest part.

We are going to need to develop an entirely new modern coal industry, with new mines that meet modern health and safety standards and have a minimum impact on the environment. It will be necessary for us to allow coal to be stripped under realistic regulations that provide for responsible reclamation of the land. It will be necessary for us to restore our railway system with new roadbeds and new rolling stock.

We will, of course, come to depend more and more upon coal gasification and liquification, but here the absolute necessity for a systems approach to an integrated national energy policy becomes overwhelmingly obvious.

Recently we had a meeting between representatives of the Institute of Gas Technology and the Atomic Energy Commission for them to understand what each other was doing in the area of coal gasification. IGT has at Chicago what is generally believed to be the most advanced gasification technology in this country, called the "high gas process". We asked these optimistic advocates of their process how soon they thought this process could be in the line, how soon they could have an economically competitive full-size demonstration plant on the line. These advocates said 1985. And then we said, "How much would it cost?" Their figures, in 1973 dollars, $400 million a plant. We made a hasty calculation of the number of plants that would be required, given the output that this plant would have. The plants that would be required just to close the gap between declining supply and the demand for natural gas alone--and this is

presently projected for 1985--the number of plants is 500.

That is $200 billion for capital alone for coal gasification plants alone in the period 1985 to 1990. In addition of course, this operation would require 140 percent of all the coal that is mined today, just for gasification, and the equivalent of 10 percent of the flow of the Columbia River for process water--not cooling water; for process water.

This totally eliminates doing this in dry land area. Now these figures may change. New technology may change them, but the principle remains. One can quickly grasp the implications of undertaking even one project of this magnitude, in terms of, for instance, coal and water and dollars and steel and manpower, both skilled and unskilled, logistics, and environmental impact. It is important to consider how each of these relates to each other and how all of them relate to the same sort of factors for every other sort of related activity just in the energy field. Coal liquification, or expanded mining, or shifting to smaller cars, or building nuclear power plants, or providing new housing, or mass transit systems are other examples.

Our systems approach to an integrated national energy policy must plan now to meet these problems for the next year and 1980 and 1985 and the year 2000. We know we won't be right in our estimates, but at least we have been looking ahead so we can see the major roadblocks, at least dimly, and start to plan for them on a year-to-year basis.

Now, it may not be apparent, but I am certain that one of the greatest strokes of good fortune that this nation has experienced is to have our nuclear industry as well advanced as we find it today, ready now to provide much of the energy this nation will need during the next 50 years. Nuclear energy is the cleanest significant source of energy available to us for the immediate future, with the least environmental impact of any significant option. That includes coal. It is both cheaper and cleaner than coal. And if we did not have the nuclear energy available to us for these coming decades, the future of this country would indeed be black in more ways than one.

Now, I puzzle some people with this, and I know I do. There are many who ask me how I can possibly support both solar and nuclear energy. Well, of course, this comes from a prejudiced standpoint. My answer is that I don't have the luxury of choosing between sources of energy when developing energy policy for this country. We must develop all sources of energy as rapidly and as responsibly as we can, finding out which ones really can be developed, which we can use, and what we can do. But each has its place, and we just cannot afford the luxury of basing policies on prejudices.

We must support both solar and nuclear. Today, by the way, there are 50 nuclear plants on the line, producing about 33,000 megawatts of electricity. But there are 58 more plants under construction and in final testing, and about 100 on order. By the mid-1980's we sould have about 200 nuclear power plants on the line producing about one-fourth of this nation's electricity. From present projections, it is assumed that by

the year 2000 we will be producing about two billion kilowatts of electricity instead of the 449 million we are producing today, and 60 percent of this will be produced by nuclear energy. Maybe with good conservation programs we will cut that down. On the other hand, as we try to reduce our dependence upon coal and petroleum, we will undoubtedly be increasing our dependence upon nuclear energy through use of electricity.

Now we must also, of course, look to the longer range with the same degree of intensity and dedication that we looked at the short-range. Here, of course, we come to solar energy and geo-thermal energy and nuclear fusion.

I am sure, from your discussions, you know that the Solar Heating and Cooling Demonstration Bill is now law; that our omnibus solar energy bill is now law, and that both of these will be phased into ERDA, as the ERDA comes into existence. We now have a clear commitment from the government to support all aspects of solar energy research and development and demonstration. It is a long-range sort of bill. It is a billion dollar bill. It will include every indirect source of solar energy such as wind, ocean thermal gradients, photovoltaics, boiconversion, thermal electric farms, waste incineration, the whole spectrum of R and D.

Here again, this is long-range. I think that while solar energy will play an important role in our future, we simply have to keep it in perspective. It is my very serious conviction that even with a well managed, well funded program for solar heating and cooling, we will do very well to have one percent of this nation's energy from solar heating and cooling by the year 1990, another one percent from other sources of solar energy.

As a knowledgeable scientist, I don't dare base my estimates on hopes or dreams of new technologies coming in and being simple enough to be developed quicker than that. But I hope that you can prove me to be too conservative. We must be conservative in making our projections and making our plans.

You can afford to dream. You can afford to experiment, you can afford to take chances on new ideas, and I hope you can prove that I am too conservative and that we can have more solar energy sooner than my estimate.

Finally, I want to speak just a minute about nuclear fusion, because here we have experienced what amounts to a breakthrough. It isn't one singe act, one single site, but a whole series of advances and a whole number of sites and Princeton, Los Alamos, Oak Ridge, and Livermore, in Texas, and various other places in the country. There is no question about the fact that the last two or three years have been the most productive in the history of controlled thermo-nuclear reserach. And certainly we are now operating on a new plateau, one which we dreamed of and sought for 20 years. For the first itme we are in a position to move forward with a much more aggressive research and development program in this area, and with considerable confidence, predict success.

It is my conviction that by the mid-1990's, about 1995 or maybe a little bit later, we can have a commercially feasible fusion electric demonstration plant on the line. But this will require massive support starting now for materials research and development and engineering studies.

If this program is successful, then maybe we will be able to look forward to providing unlimited quantities of clean, cheap energy forever, not only for this country, but for all mankind.

The same is true for solar energy. We know it's there. All we have to do is figure out ways to get it into usable form. Legislation has been passed. We are now a long way ahead of where we were 18 months ago when I spoke to you the last time. At that time we talked about hoping to write legislation. Now this legislation is law, the programs are in place, the money has been authorized, the support has been developed, and I am convinced that we can now move forward.

I believe that we can develop solar energy to play an important role in this nation's energy picture by the 1990's or the year 2000. But you have a very special responsibility, and I want to put it on you.

First of all, pursue solar energy applications with enthusiasm and dedication, to make these dreams come true. And secondly, at the same time, help the public understand its role, the role of solar energy, and the fact that unless we do have startling developments, it is a long-range, future source of energy.

We must today have a systems approach to a comprehensive national energy policy, depending upon all forms of energy. We cannot use just one energy source. I want to thank you again, ladies and gentlemen, for having me here today. We will be continuing to work with you. This is an all day thing every day for us in my committee and with my staff, in working together with you, with the National Science Foundation, with NASA, with HUD, with the Office of Management and Budget to provide the funds.

We encourage you to submit your questions and your problems to us. We will do anything we can to help get these programs going.

SESSION 7

TESTING AND STANDARDS

PROPOSED METHOD OF TESTING FOR RATING SOLAR COLLECTORS BASED ON THERMAL PERFORMANCE

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The National Bureau of Standards has made a study of the different techniques that could be used for testing solar collectors and rating them on the basis of thermal performance. The result of the study was the development of a standard test procedure where the efficiency of the collector is obtained under "steady-state" conditions. The series of tests that comprise the testing procedure is conducted outside under real sun conditions* and the results of the tests are displayed in graphical and tabular form.

There have been other attempts at describing a standard test for solar collectors [1, 2, 3] with the most recent work done by the University of Pennsylvania [3] summarized at this workshop [4]. Considerable experience also exists in testing solar collectors in Australia [5, 6] and in this country at the NASA Lewis Research Center [7, 8, 9] and at Honeywell Corporation [10]. In addition to the procedure outlined in reference [1], C.S.I.R. of South Africa has also developed a three week testing procedure for solar water heaters where a collector and storage tank are tested together as a single unit [11, 12].

The test procedure developed at NBS [13] has been written in a format consistent with other standards of the American Society of Heating, Refrigerating and Air-Conditioning Engineers. The outline of the document is as follows:

Section

1	Purpose
2	Scope
3	Definitions
4	Classifications
5	Requirements
6	Instrumentation
7	Apparatus and Method of Testing
8	Test Procedure and Calculations
9	Data to be Recorded and Test Report
10	Nomenclature
11	References

with the major portion of the document being in Sections 5 through 9.

The test procedure is limited to collectors that can be isolated so that they have effectively one inlet and one outlet. The energy of the fluid entering and leaving the collector can then be determined by making appropriate measurements. These quantities are then compared to the energy in-

* The testing procedure itself is equally applicable for testing indoors using a solar simulator; however, the present version of the document does not list the requirements for such a facility.

cident upon the collector (also determined by measurement) in order to calculate the collector efficiency. The fluid can be either a liquid or a gas but not a combination of the two.

The document specifies the apparatus to be used when a liquid (Figure 1) or air (Figure 2) is to be the transfer fluid. The detailed requirements of the apparatus are given along with specifications for instrumentation to be used in measuring incident solar radiation, temperature, temperature difference, liquid flow rate, air flow rate, pressure, pressure drop, time, and weight.

The series of tests consists of determining the average efficiency for 15 minute periods (integrating the energy quantities) over a range of temperature differences between the average fluid temperature (average of inlet and outlet) and the ambient air. The test apparatus has been designed so that the temperature of the fluid entering the collector can be controlled to selected values. This feature is used to obtain the data over the temperature range desired. At least sixteen "data points" are required for a complete test series and they must be taken symmetrical with respect to solar noon (to prevent biased results due to possible transient effects).

During each test period, the incident solar radiation must be "quasi-steady" as indicated in Figure 3 (in contrast to days in which cloud cover can cause a time distribution such as shown in Figure 4). Other requirements that must be satisfied for each "data point" are that the 15 minute average insolation be greater than 630 W/m^2 ($\approx$ 200 Btu/hr ft^2) and the incident angle between the sun and the outward drawn normal from the collector be less than 45°. In addition, the range of ambient temperatures for the entire test series must be less than 30 C (54 F).

The measurements made and the calculated efficiency for each "data point" are reported in tabular form as well as in graphical form as shown in Figure 5. The ordinate is the efficiency and the abscissa is the measured temperature difference divided by the insolation. It is recommended that the units be standard SI or that the abscissa be made dimensionless by dividing the temperature difference by either 100 C or 212 F and the insolation by the solar constant.

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12. Chinnery, D. N. W., "Solar Water Heating in South Africa", CSIR Research Report 248, UDC 694.4:551,521.1 (680), Pretoria, South Africa, 1967.

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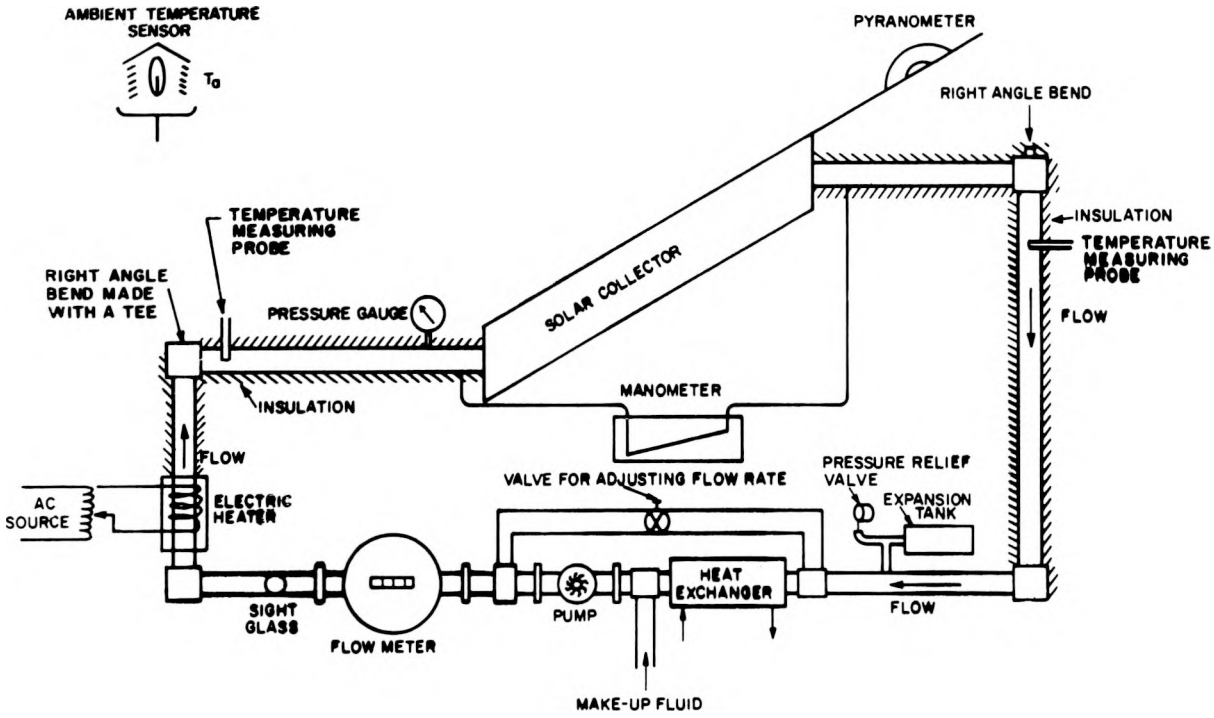


Fig. 1 -- Testing Configuration for the Solar Collector When the Transfer Fluid Is a Liquid

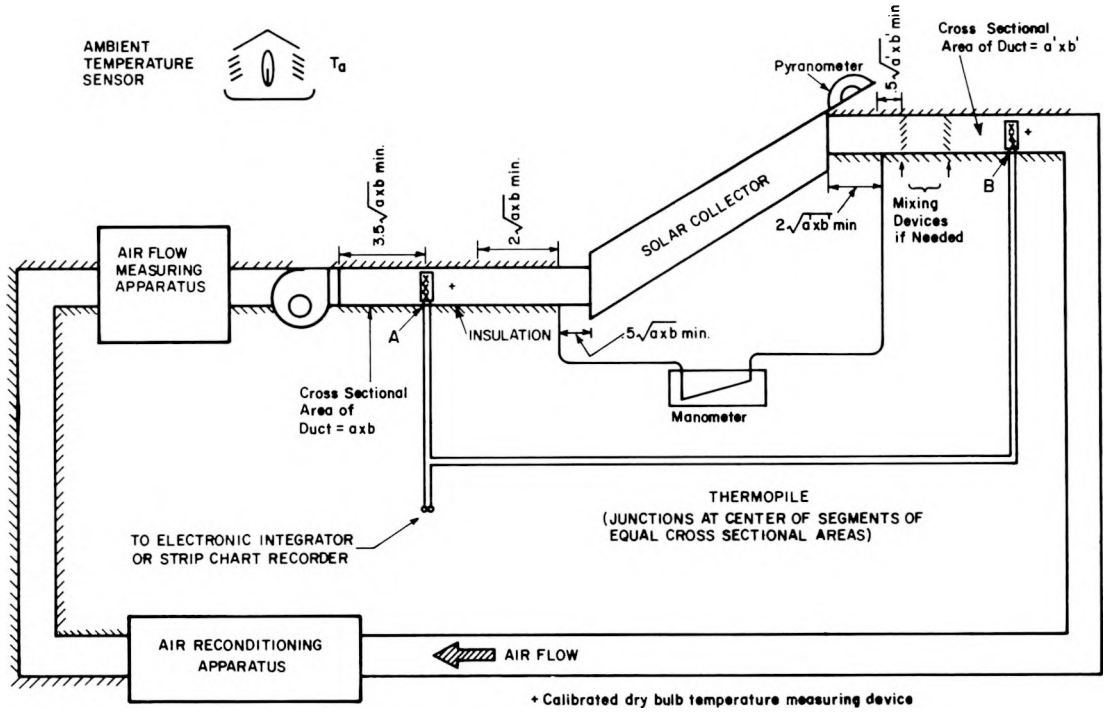


Fig. 2 -- Testing Configuration for the Solar Collector When the Transfer Fluid Is Air

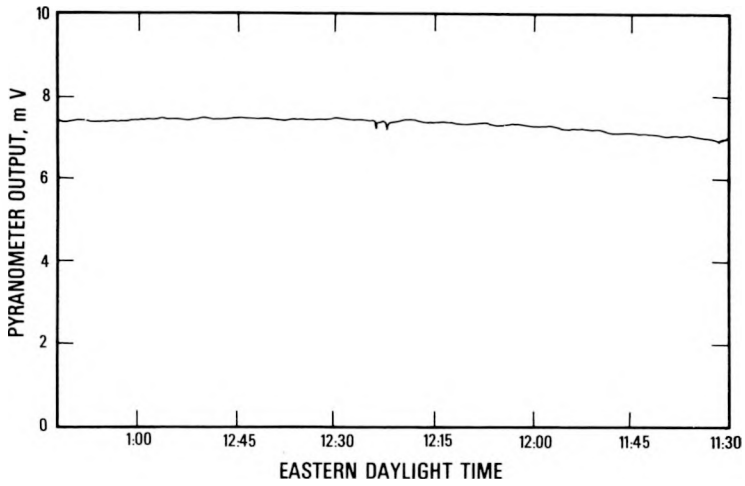


Fig. 3 — Incident Solar Radiation on a Horizontal Surface at the National Bureau of Standards Site in Gaithersburg, Md., March 13, 1974

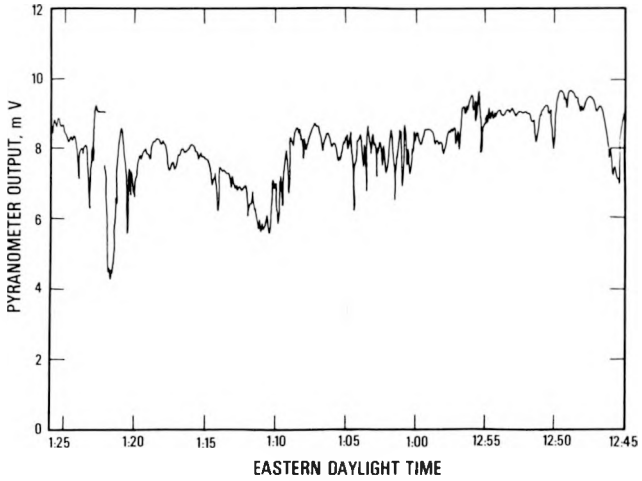


Fig. 4 — Incident Solar Radiation on a Horizontal Surface at the National Bureau of Standards Site in Gaithersburg, Md., March 11, 1974

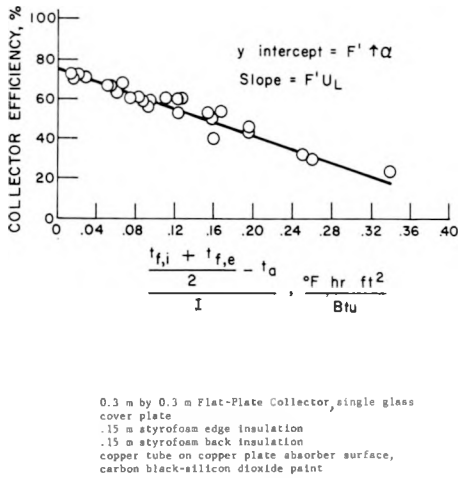


Fig. 5 — Efficiency Curve for a Flat Plate Collector Using Water as the Transfer Fluid (Ref. 7)

DISCUSSION

Question (William Beckman, University of Wisconsin): The Hottel-Whillier-Bliss model does not use the average fluid temperature but the inlet temperature. (The average temperature is used in the Hottel-Woertz model.) If you use the inlet temperature, F' must be replaced by F_R. Why did you select the average temperature instead of the inlet temperature?

Answer (James E. Hill, National Bureau of Standards): The average temperature was selected because we felt that it gives a better indication of the heat loss rather than the inlet or outlet temperature.

Question (Carleton Granbery, Architect): NBS test standards have been here criticized as being inadequate, misleading, not in accordance with congressional directives, and focused on components rather than systems. Would you kindly respond to this criticism?

Answer: The criticism obviously stemmed from a misunderstanding. The test procedure described at this workshop was developed in accordance with a directive from the National Science Foundation to develop a test procedure for solar collectors. The congressional directives referred to in the criticism relate to an entirely separate program—the Solar Heating and Cooling Demonstration Act of 1974.

Question (Harold R. Hay, Skytherm Processes): When will you develop ratings of collectors that *do* combine collector and storage?

Answer: We plan to develop test procedures for total systems in which solar collectors and storage devices are components as part of our work on the Solar Heating and Cooling Demonstration Act of 1974.

Question (Mr. Hay): Will the lack of criteria on a system that *does* combine collection and storage retard use of such systems in the HUD/NASA program of early demonstration?

Answer: If you examine the document "Interim Performance Criteria for Solar Heating/Cooling Systems and Dwellings" that we have developed for HUD, you will find *no lack* of criteria on systems.

Question (John I. Yellott, Arizona State University): Has any thought been given to determining day-long performance of a thermosiphon heater?

Answer: NBS has not developed a test procedure for a thermosiphon heater; however, the South Africans have developed one, and it is described in "Solar Water Heating in South Africa," D. N. W. Chinnery, *CSIR Research Report* 248, UDC 694.4: 551, 521.1 (680), Pretoria, South Africa, 1967.

Question (Eugene E. Drucker, Syracuse University): Collector efficiency will generally depend on cloud cover. How is this factored into the proposed test standard?

Answer: At the present time, the effect of cloud cover on collector efficiency is not explicitly determined. However, one is required to record the percentage of incident radiation that is diffuse for each "data point."

Question (Richard B. Bannerot, University of Houston): Proposed testing seems to consider only efficiency or total collected energy. How will concentration effects, i.e., absorber-plate temperature, be weighted against efficiency?

Answer: The effect of absorber-plate temperature on efficiency is accounted for in that the average fluid temperature between inlet and outlet is one of the variables in the abscissa of the efficiency curve to be plotted.

Comment (Karl W. Boer, University of Delaware): For performance judgment, collector efficiency and pumping energy requirements are important for air collectors. It is suggested to develop in addition to η a quality factor,

Q. Examples may be:

$$Q_\eta = \frac{\text{Thermal Energy}}{\text{Solar Energy in} + K \times \text{elect. En. for pumping}}$$

or

$$Q_E = \text{thermal energy out} - K \times \text{elect. En. for pumping}$$

with K much larger than 1, taking into consideration the higher value of elect. energy.

Reply: This is a good suggestion. We have recently made an addition to the test procedure so that the theoretical pumping power must be calculated and reported using measured flow rate and measured ΔP. We have not gone as far as you suggest and actually had a Q coefficient or C.O.P. calculated (as suggested by one of our reviewers).

Question (Jeffrey S. Rauch, Motorola, New Ventures): Could you comment on the required overall system accuracies for temperature and flow measurements?

Answer: Absolute temperatures must be measured accurate to ±0.5C (±0.9F), temperature difference accurate to ±0.1C (±0.2F), and liquid-flow-rate measurements accurate to ±1.0 percent of the measured value.

Question (Mr. Rauch): Could you comment on the use of an efficiency based on gross rather than absorber area?

Answer: Basing the efficiency on gross area is probably the most meaningful for designers, since gross area is the governing factor in how much the collector can actually be deployed. Basing the collector efficiency on absorber area is probably more theoretically correct.

Question (Mr. Rauch): The preferred units of the ordinate—wouldn't it be desirable to make this dimensionless?

Answer: Yes.

Question (Forrest S. Higgs, A.I.A. Research Corporation): Where are the test standards for focusing collectors that were mentioned in your table of contents?

Answer: The focusing collectors can be tested using the same procedure. Where differences exist in the test for flat plate collectors versus focusing collectors, they are noted in the document.

Question (Mr. Higgs): When will standards for boiling fluid collectors of both focusing and nonfocusing types be available?

Answer: We have no plans at present for expanding our test procedure or developing a new procedure to cover collectors in which the transport fluid boils.

Question (Mr. Higgs): How are sidewall-shadowing effects on flat plate collectors, which occur in a normal operating regime, taken into account?

Answer: If shadowing effects occur in normal operating conditions, they will occur during testing.

Question (Jan F. Kreider, Environmental Consulting Services): How do the proposed collector standards differ for flat plate and focusing collectors? Please describe the focusing collector standard very briefly.

Answer: They do not differ in any significant way. Both types of collectors are tested using the same procedure.

Comment (Thomas B. Reed, Massachusetts Institute of Technology): (a) The Hottel-Woertz equation does not imply a straight-line relation between efficiency and ΔT. (b) We find heat losses vary between $(\Delta T)^{1.2}$ and $(\Delta T)^{1.5}$,

depending on gas pressure, optical properties of absorbing and transmitting surfaces, and geometry. (c) Therefore let us present actual data on collector performance and not fit them to a straight line of any other preconception.

Reply: The person conducting the tests is asked to plot η versus $\Delta T/I$. He is not required to make the resulting plot a straight line.

Question (Unidentified): Collector performance is influenced by the installation, i.e., insulation of pipes, edge of the collector, and back of the collector. Also, if the collector is assembled on site the sealing of the collector can be important. How do you plan to cope with this in establishing performance criteria?

Answer: The document states that "If the collector is modular and the test is being done on one module, it should be mounted and insulated in such a way that the back and edge losses will be characteristic of those that will occur during operation on a structure."

Question (Gary Brockett, International Heating and Air Conditioning Division): Standards discussed are for rating methods of solar panels. Because of the responsibility of a manufacturer to produce a safe product, particularly since the creation of the Consumer Product Safety Administration, should there not be a preliminary safety standard? This will insure safety incorporated in design rather than as an afterthought.

Answer: I believe there should be. However, it was outside the scope of the present project.

Question (Frank Kreith, Environmental Consulting Services): Does the NBS rating program provide for consumer protection against exaggerated claims?

Answer: That sort of thing will be covered after it is determined just how the document will be accepted and adopted by standards-making bodies.

53/115

SOLAR COLLECTOR TESTING AND STANDARDS

by

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I. Standards for Solar Equipment

The production and utilization of conventional flat plate solar collectors is fairly simple. This is obvious both from observing their design and from experience in this and other countries. Many small manufacturers, mainly those with sheet-metal work and plumbing capabilities have indeed joined with relative ease in producing solar collectors and entire solar water heating systems. In view of the purchased energy savings, as well as of the simple installation, utilization and maintenance, the solar systems were rapidly adopted by a large number of apartment and home owners in such countries as Israel, Australia and South Africa, to name a few, and are apparently gaining in popularity in the USA.

The introduction of a new and potentially popular product introduces significant difficulties for all who are involved in the manufacturer-customer chain. In particular, the customer may be faced by heavily advertised solar products from many manufacturers, without being able to clearly understand the non-uniform performance criteria which may be used, and by insecure feelings about the durability and reliability of the products. At this point, the establishment and utilization of standards which clearly specify quality, performance and the methods for their evaluation is of paramount benefit in alleviating many of these difficulties and, thus, in assisting to implement the widespread use of solar energy. It may be worth bearing in mind that the potential benefits of solar energy utilization extend also beyond the economical considerations of the private sector, acting in support of the national policy of energy independence.

From the viewpoint of the customer, the standards would:

1. Provide greater confidence and assurance of:
   a. Product performance (such as quantity of heat or hot water that can be produced per unit area of collector, under various weather conditions)
   b. Product quality, most significantly durability, reliability, maintainability.
2. Provide a definite and legal basis for return or redress
3. Broaden fair competition
4. Reduce inspection effort or cost
5. Provide a recognized basis for comparison of values [cf. Ref. (1)] .

In the distribution chain (jobber, wholesaler, retailer), the standard provides:

1. Factual basis for:
   a. Selection of stock
   b. Advertising and selling
   c. Adjustment of complaints
   d. Protection of reputation and prestige
2. Increase in confidence and good will by same means.

For the manufacturer, the standard clearly specifies the testing procedure and techniques and assists his marketing effort by:

1. Increasing his confidence, mainly through providing an honest, straight-forward, openly-arrived-at, nationally recognized basis for daily trade.
2. Establishing a well recognized basis for certification of quality and performance.
3. Increasing confidence and good will among customers, mainly due to the certified quality and performance of the product.
4. Providing facts for effective advertising.

In view of the rapid change and development in solar collector designs, it does not seem that standards should, for the time being, also clearly specify the design or shape of the solar collector and associated equipment. The standards ought to be confined at present to specifying the quality and performance of the equipment, as well as the methods for their evaluation.

The major obstacle confronting widespread utilization of solar energy is the capital cost involved and the major efforts in this field are in the reduction of this cost per unit performance. This consideration must be one of the major guidelines in the establishment of the standards. Testing techniques that are cost-effective should be devised, to minimize the cost added to the solar equipment due to testing. In order to achieve this objective, it is of primary importance to precisely and judiciously identify the goals of the tests, namely to identify the criteria of quality and performance. The testing techniques can be devised and made cheaper only after these criteria are properly identified. Obviously, testing which is complex or not objective-oriented is counter-productive, and, furthermore, serves to repel manufacturers and customers alike.

Some existing standards (2,3) a proposed interim standard (4), and related papers (5,6) are listed with the references. It also came to our knowledge that the NBS is working on such standards for the NSF, but no copies were made available yet.

II. Quality and Performance Criteria

Quality criteria are not unique to solar equipment and would thus not be discussed in detail. They should include provisions for testing for influence of external and internal corrosion, weatherability, durability and dependability. Some of the more important items are the quality of the window panes and of the absorber coating in the collector, and the

retention of heat storage capability in phase-change thermal storage materials.

The major difficulty lies in the establishment of a performance criterion for the solar collector. The criterion which is most frequently encountered through the literature is the instantaneous collector efficiency η,

$$\eta = \frac{\text{Heat collected by collector}}{\text{Solar energy incident on collector}}$$

This definition of efficiency is not too meaningful because it depends strongly on the insolation and on the temperature difference between absorber and ambient, and depends to varying extent on solar incidence angle, wind, atmospheric humidity, ratio of diffuse to direct insolation, etc. Essentially, to convert the efficiency to an operational value which is meaningful to the customer, such as quantity of heat or hot water made available, would require the specification of all the above parameters, for every time element of each day.

Some generalization, which made η somewhat more useful, was obtained when Hottel & Whillier (7) and Whillier & Richards (6) observed a linear relation between η and the ratio $\frac{\Delta T}{I}$ where ΔT is the temperature difference between the absorber (or collector fluid) and the ambient, and I is the insolation. This linear relationship is reasonably good for conventional designs of collectors (cf. Fig. 1), but fails for collectors where the properties depend strongly on the direction of incident solar radiation, such as with these incorporating cellular structures between window and absorber, or having selective black absorbers. This is seen clearly in Fig. 2, obtained for a collector incorporating reflective honeycombs.

Ref. (4) proposed the utilization of the Diurnal Heat Capacity Rating as an operationally meaningful criterion for the customer. It indicates the effective quantity of heat collected during one day of each month during which solar collection is needed, at the general locality at which the collector is to be used. The collector undergoing test would be oriented due South, at an inclination angle equal to (Northern Latitude Angle) minus (Solar Declination Angle). The "typical" day would be equivalent to the 21st of the month, for which insolation values are given in the ASHRAE handbook (8). The ambient temperature shall be the known daily average temperature for that day (or period), obtained from published data. The temperature(s) and flow rate(s) of the heated fluid would be those specified by the manufacturer. Weather conditions during tests shall be such as to exclude days with excessive dust, mist, and excessive cloud cover and wind. If the test is interrupted during the day, the Diurnal Heat Capacity Rating can be determined as composed of part-day tests run over several days, provided the weather and insolation conditions remain similar. The results would be reported in a form similar to Table I.

The refinement of this criterion is still in progress; for example, it is being investigated whether large geographic areas in the U.S. could be "lumped" into zones for which this

criterion would remain valid.

It seems that significant further work should be invested into the establishment of relevant performance criteria which are also not too expensive to measure.

III. Test Methods

Methods for testing solar collectors can be classified into

1. Absolute vs. Relative
2. Continuous vs. "Calorimetric"
3. Continuous; Closed Cycle vs. Open Cycle

In the "relative" method, the performance of all collectors is measured simultaneously with that of a reference collector, and the performance is thus determined in comparison to (or relative to) the reference one. In this method, all collectors have the same area, are oriented in the same direction, are located close together under the same ambient and insolation, and usually the inlet temperature and flow rate of the heated fluid are the same for all. This method is very effective in solar collector development and in comparing various designs. It, of course, can also provide the data for the absolute performance of each collector tested.

In the "continuous" method, the heat collection rate is determined by measuring the flow rate and temperature difference of the heated fluid across the collector continuously. In the "calorimetric" method the heated fluid is stored in a tank throughout the test period and the heat collection is determined by measuring the increase in stored heat in the tank, at the end of the test period. The "calorimetric" method is somewhat simpler, not requiring continuous records, integration and flowmeter. On the other hand, providing only integral values, it does not provide continuous information on the heat collection process, which may be necessary, particularly in new designs.

In the "continuous closed cycle" method, "continuous" measurements are made and the fluid heated in the collector is recirculated after rejecting the heat to the ambient by means of a heat exchanger. In the "continuous open cycle", continuous measurements are made but the flow is "once-through", introducing new fluid and dumping it continuously. The open cycle system does not require a heat rejector, but it wastes the fluid and required continuous fluid pretreatment, such as filtering, deionization, degasing etc.

The parameters to be measured in the "continuous" methods usually consist of

1. Temperatures:
   a. Fluid inlet or outlet
   b. Ambient
2. Temperature Differences:
   a. Fluid outlet - Fluid inlet
   b. Fluid inlet - Ambient
3. Fluid flow rate
4. Insolation

To get the needed accuracy, it is desirable to measure the temperature differences directly, by such methods as a differential resistance thermometer bridge or between the junctions of a thermocouple or thermopile. For insolation, a pyranometer which measures total direct and diffuse insolation is usually adequate, provided the necessary precautions, such as compensation for ambient temperature change and angle of inclination, are taken. It ought to be used adjacent to and in the same plane as the collectors.

Extensive experimental studies performed on a large number of solar collectors at the National Center for Energy Management and Power of the University of Pennsylvania (9) have utilized all the above methods (cf. Figs. 3,4,5) except for the "calorimetric", which is recommended in (2) and (3). For those who are well versed in thermo-fluid measurement techniques, the measurements were rather straightforward and did not require much experience unique to this problem. Moreover, most of the measurement techniques are covered by various standards and recommended practices (ASME, ASHRAE, ISA).

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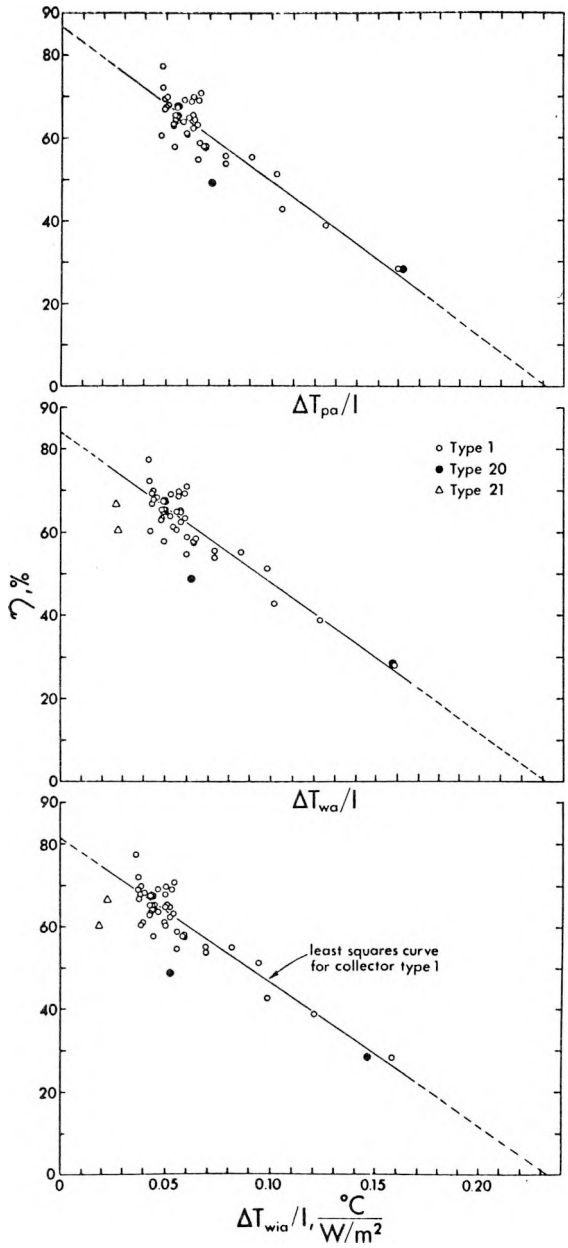


Fig. 1 – Collector Types 1, 20, and 21; Efficiency vs. Ratio of Temperature Difference to Insolation (Ref. 9)

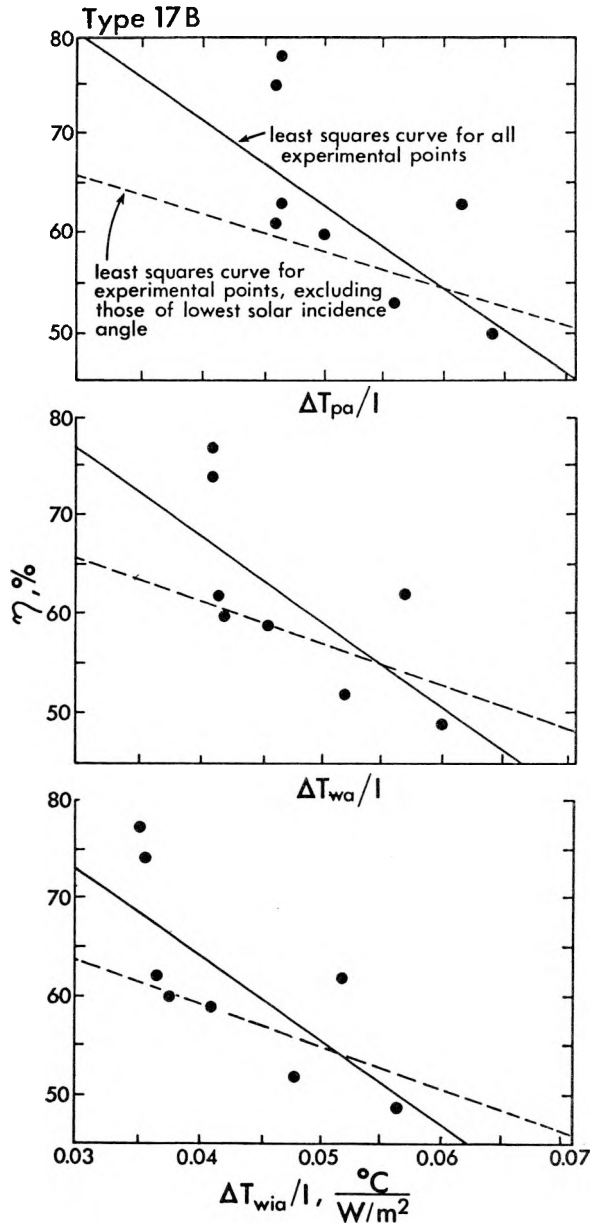


Fig. 2 – Collector Type 17B; Efficiency vs. Ratio of Temperature Difference to Insolation (Ref. 9)

Table I

Heat Capacity Rating

(Ref. 4)

Fluid inlet temperature = _____ **Fluid:** _____

Equivalent Date	Total Insolation	Fluid Outlet Temp.	Ambient Temp.	Mass flow rate	Diurnal Heat Capacity Rating
21 January					
21 February					
•					
•					
•					
•					
•					
•					
•					
•					
•					
21 December					

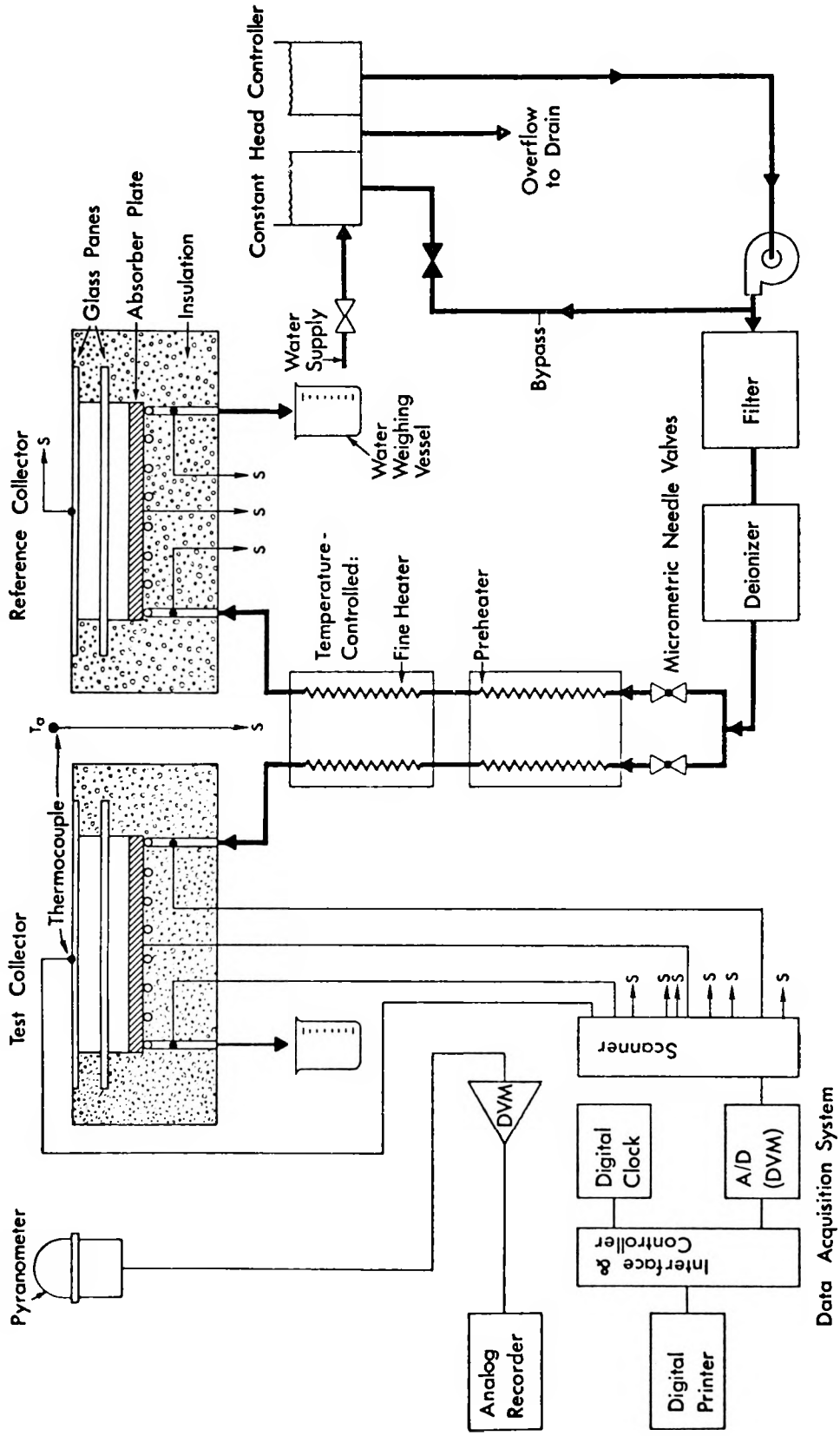


Fig. 3 — University of Pennsylvania Solar Collector Comparative Test Facility ("Comparative Continuous Open Cycle" Method) (Ref. 9)

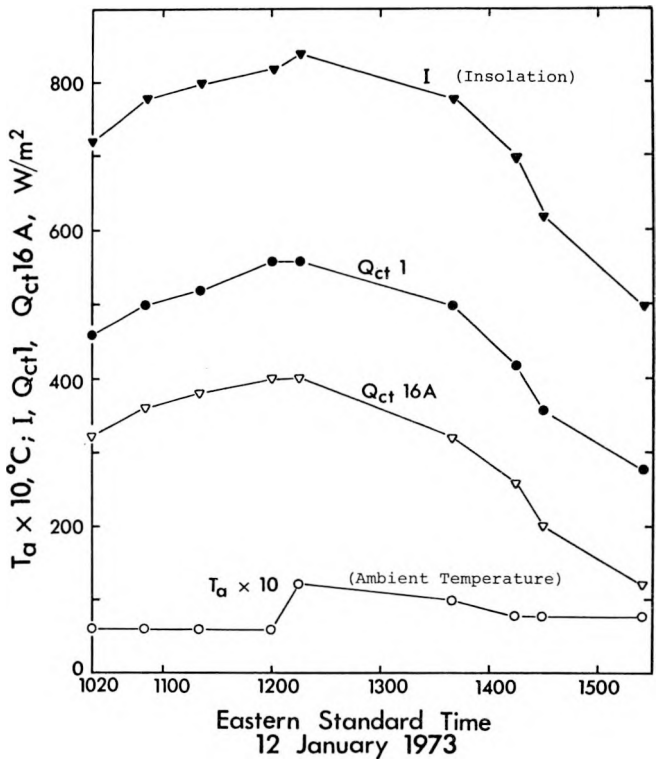


Fig. 4 — Energy Collection Rates Q_{ct}, Collector Type 1 vs. Type 16A; 12 January 1973 (Comparative Tests) (Ref. 9)

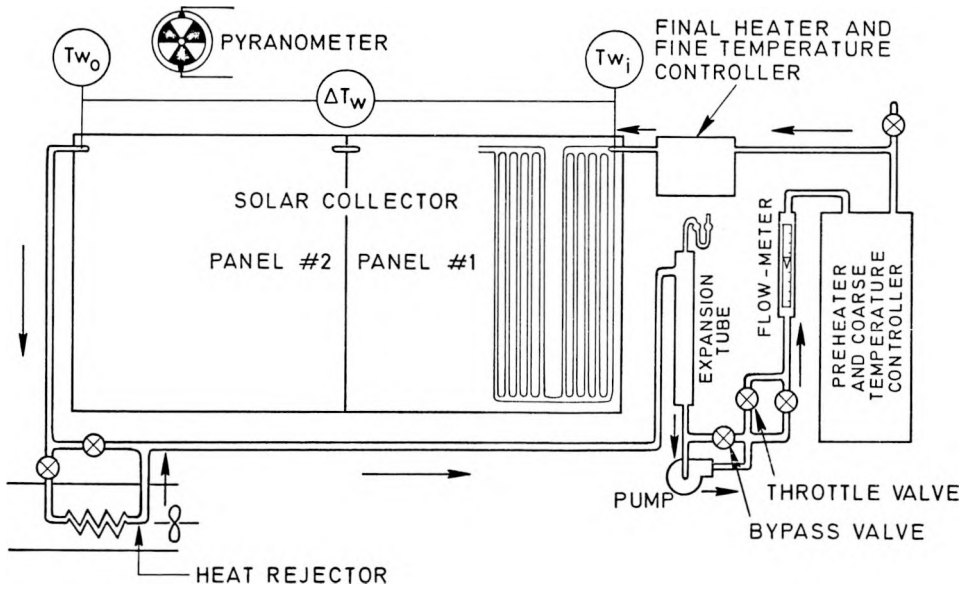


Fig. 5 — University of Pennsylvania 4 x 8 ft Module Prototype Solar Collector Test Facility: Flow Diagram ("Absolute, Continuous Closed Cycle" Method) (Ref. 9)

DISCUSSION

Question (David Waksman, National Bureau of Standards): With your test method, how do you compensate for the changes in the efficiency of directionally sensitive collectors that would occur as a function of latitude, time of year, and the ratio of diffuse to normal incident radiation which is a function of climatic conditions?

Answer (Harold G. Lorsch, University of Pennsylvania): According to our proposed test method, collectors that are designed to operate in a predetermined orientation shall be tested in the same orientation relative to the solar trajectory, compensating for differences in geographic latitude if the location of the test facility and that of the eventual use of the collector differ by more than 10° in latitude.

Collectors designed for general use shall be tested when oriented due South, at an inclination angle equal to (Northern Latitude Angle-Solar Declination Angle).

The intensity of solar radiation incident on the collector as measured by a global pyranometer shall be within ±15 percent of that given by the ASHRAE (1974) tables for the 21st day of each month of interest. Days with excessive dust, mist, or other particles in the air, as well as days with more than 20 percent cloud cover, shall be avoided.

The proposed test method attempts to utilize conditions that are as close to the operational ones as possible. Collector testing and utilization should therefore occur in geographic zones that have similar weather conditions. Since the diffuse radiation is usually a small part of the total, these geographic zones may be rather extensive.

Question (Douglas M. Burch, National Bureau of Standards): It is well known that the optical efficiency of a flat plate collector is a function of the incident angle of the solar insolation. Your test procedures propose to compare the performance of different collectors by use of the measured daily average collector efficiencies. How do you account for differences in diurnal absorbed solar radiation due to variations in the amount of cloud cover occurring at different hours of the day?

Answer: Testing would be conducted only when cloud cover is less than 20 percent, as indicated in the answer to Mr. Waksman.

Question (John A. Duffie, University of Wisconsin): To test a collector over a day implies that the inlet fluid temperature to the collector is fixed or known. In most cases this is not known, and collector performance over a day cannot be projected independently of the balance of the system. How do you propose to assure a customer of performance of his collector without knowing how he will use it?

Answer: The proposed operational test method provides substantially more useful information to the collector customer and manufacturer than the instantaneous efficiency. However, even the operational method has some practical limitations that are the consequence of a compromise between attempting to repeat precisely the conditions of ultimate utilization and a simple and relatively inexpensive test procedure. As Dr. Duffie remarked correctly, the temperature of the collector usually varies during operation, and depends on the overall system and on its control strategy. Thus, when the temperature of utilization is unknown to the manufacturer, it would be proposed to conduct the test at three constant collector inlet temperatures of 100° F, 150° F, and 200° F. This procedure would bracket the performance of the collector adequately, if the customer is familiar with the temperature range of his particular collector during actual operation.

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A BRIEF REVIEW OF MATERIAL PROPERTY MEASUREMENTS FOR SOLAR COLLECTOR COMPONENTS

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The design and development of solar collectors requires detailed material properties of the components to predict performance, compatibility and durability. For commonly available materials, data may be required only for the effects of a particular environment and the design, fabrication and full scale testing can proceed with confidence. However, for applications involving new materials or the optimization of systems, a large number of property measurements may be desirable prior to full scale fabrication.

This brief review is of data requirements and some of the accepted measurement techniques which have been developed primarily in the thermophysics field for thermal control applications. Data requirements can generally be classified into three categories as shown in Table I. The thermophysical properties include thermal conductivity, specific heat and the thermal radiative characteristics. Physical properties cover the density, tensile strength, melting point and other common properties. The environmental resistance of materials to solar ultraviolet radiation, moisture and possible pollutant gases are particularly significant for collector materials.

Techniques for measuring the common thermophysical properties shown in Table II are primarily accepted American Society for Testing Materials (ASTM) Standards and complete descriptions of the apparatus and procedures are available in ASTM publications. The test apparatus can be procured from specialty manufacturers or custom made in the laboratory. Specific heat and expansion coefficient measurement procedures are described in commonly available physics texts.

One of the largest uncertainties in designing solar collectors arises from the varying spectral distribution of solar terrestrial energy. As shown in Figure 1, the reduction in flux and the shift toward longer wavelengths occurs with increasing air mass* Air mass 2 has been adopted by ASTM as the reference spectral distribution and as the basis for calculating total terrestrial optical properties such as solar transmittance. Spectral optical properties are particularly important when calculating

* Air mass is a function of solar zenith angle and the corresponding spectral distribution results from the increased atmospheric absorption and scattering as predicted by an analytical model.[1]

energy transfer with selective coatings. As illustrated in Figure 2, integration of the spectral solar absorptance over the total wavelength region from 0.3 to 1.8 micrometers (um) is required to obtain an accurate value. If measurements were only made in the 0.4 to 0.6 μm range, the same solar absorptance value would be calculated, for each material.

Solar optical property measurement techniques are summarized in Table III and include reflectance, transmittance and calorimetric methods. The less accurate ASTM integrating sphere methods use a double-beam spectrophotometer. The more precise Gier-Dunkle integrating sphere employs a single beam monochrometer for less uncertainty[2]. Detailed descriptions of both spectral and calorimeteric techniques employed in the space program have been reported.[3,4]

Similar requirements for spectral data arise when evaluating wavelength selectively emitting coatings. Increases in temperature results in a shift in the spectral energy distribution to shorter wavelengths which can be integrated with the spectral emittance to determine the total emittance at any temperature. When precise values of total hemispherical emittance are required, a calorimetric technique has been shown to be the most accurate.[5] A comparison of emittance measurement techniques is presented in Table IV. For fast measurements suitable for quality control, portable relatively inexpensive commercial instruments are available.

After careful characterization of the optical properties, the susceptibility to degradation by exposure to in-service environmental conditions is necessary. Although only limited experience is available regarding terrestrial simulated optical property exposure test methods, it is expected that accelerated field and laboratory tests will be developed. Table V lists environmental effect tests adopted by ASTM that can presently be applied to covers, metals, heat transfer fluids, and sealants. The influence of exposure to the equivalent of 1000 hours of ultraviolet radiation in the 0.2 to 0.4 um wavelength range is shown on a translucent fiberglass sheet material in Figure 3. The diffuse transmittance measured with a single beam monochromator and a Gier-Dunkle integrating sphere indicates the development of an absorption edge in the region of 0.4 um. Although, the discoloration has only produced a small change in solar transmittance from 0.90 to 0.88, gradual shifting to longer wavelengths by the edge could result in significant absorption.

The transmittance of the 2 glass specimens also shown in Figure 3 showed a difference of about 2 percent. The material is a commercial window glass processed at two different plants by the same manufacturer.

In conclusion, as solar radiation collectors become more sophisticated to improve the performance and meet reliability and durability requirements, accurate and standard measurement techniques for industry use must be adopted.

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TABLE I COLLECTOR MATERIAL PROPERTIES

Item	PROPERTY																
	Thermophysical							Physical					Environmental				
	k	C_p	σ	α_s	τ_s	ρ_s	ε_t	D	T_s	MP	F	P.C.	UV	O_2	SO_2	H_2O	Emt.
Cover	X	X	X	X	X	X	X	X	X	X	X		X	X		X	
Absorber Plate	X	X	X				X	X	X					X	X	X	X
Coatings (AR, R, α)				X	X	X	X			X			X	X	X	X	
Insulation	X	X						X			X					X	
Heat Transfer Media	X	X	X	?	?			X			X	X					
Sealants	X		X						X	X	X		X	X	X	X	
Miscellaneous (piping, fittings, supports)	X		X					X	X	X	X					X	X

k = thermal conductivity, C_p = specific heat, σ = expansion coefficient, α_s = solar absorptance, τ_s = solar transmittance, ρ_s = solar reflectance, ε_t = total emittance, MP = melting point,

T_s = tensile strength, D = density, F = flammability, P.C. = Phase Change

TABLE II THERMOPHYSICAL PROPERTY MEASUREMENTS

Property	Apparatus	Temperature Range (^{o}F)	Property Range	Max Uncertainty	Sample Configuration	Material Type
Thermal Conductivity	7" dia Guarded Hot Plate ASTM C-177	-315 to 1000 ^{o}F	0.01 to 1 $\frac{Btu}{HR\ Ft\ ^{o}F}$	$\pm$ 5%	2-7" dia disc 5/8" thick	Insulation or Dielectric
"	Heat Flow Meter ASTM C-518	-50 to 1000 ^{o}F	0.1 to 2 $\frac{Btu}{HR\ Ft\ ^{o}F}$	$\pm$ 8%	Flat - exact size dependent on meter	Building Board Materials
"	Cut-bar ASTM C-408	60 to M.P.	1 to 200 $\frac{Btu}{HR\ Ft\ ^{o}R}$	$\pm$ 5%	1/2" x 1/2" cylinder	Relative method for metals & ceramics
"	Pipe Insulation ASTM C-335	100 to 700	0.01 + $\frac{Btu}{HR\ ft\ ^{o}F}$	$\leq \pm$ 5%	3' or longer	Fibrous Insulation
Liquids	Liquids ASTM D-2717	depend on fluid vapor pressure less than 200 torr	———	repeatibility 10%	fill glass tube 0.4 x 6" 10.7 x 152 mm)	must be compatible with borosilicate glass and platinum
Differential Expansion	Quartz Tube Dilatometer	-400 to 1800 ^{o}F	Solid Materials	1410^{-5} in./in.	3" dia 1" to 4" long	----------
Specific Heat	Ice Mantel Calorimeter	70 to 1000 ^{o}F	Unlimited	$\pm$ 1% Enthalpy $\pm$ 5% Heat capacity	20 gm min.	C_p computed from enthalpy

TABLE III SOLAR OPTICAL PROPERTY MEASUREMENTS

Property	Apparatus	Temperature Range (^{o}F)	Property Range (Micrometers)	Max. Uncertainty	Sample Configuration	Comment
Solar Absorptance or Reflectance	Integrating Sphere ASTM E-429	70	0.27 to 1.8	$\pm$ 0.02 reflectance units	1/2" to 1" disc	Opaque sample normal only
	Gier-Dunkle Integrating Sphere Model SP 210	70	0.23 to 2.4	$\pm$ 0.01 reflectance units	1" dia disc	Opaque sample angular
	Calorimeter and Solar Simulator ASTM E-434	-100 to 1500	0.3 to 2.7	$\pm$ 0.03	1" dia disc or larger	Calculated from α_s/ε ratio when ε is known
Solar Transmittance	Pyranometer in Black Box ASTM E-424 & ASHRAE #74-73	70	Total	$\pm$ 0.05	24" square or larger	Will vary with diffuse component
	Integrating Sphere Gier-Dunkle Model SP 210	70	.23 to 2.4	$\pm$ 0.01	1" dia disc	Mount sample in entrance aperture
	Integrating Sphere ASTM E-424	70	.39 to 2.1	$\pm$ 0.02		Use MgO standard
Ratio of α_s/ε	Calorimetric ASTM E-434	-100 to 1500	0.3 to 2.7	0.10	1" dia disc or larger	Requires good solar spectral match, critical to temp. measurement

TABLE IV COMPARISON OF TECHNIQUES FOR MEASURING EMITTANCE

Method	Wavelength (μm)	Reported Error		Angle	Sample Configuration	Comments
		Low ε	High ε			
Calorimetric Total hemispherical Heat balance	All	.002	.015	All	1" dia disc to 4" square	Resistance heating, edge guards, critical Temp. measurement
Total hemispherical Transient	All	-	± 0.05	All	dependent upon source and chamber	Radiant heat, uncertainties in temp. measurement and decay curve slope
Reflectance Heated Cavity	2-26	0.01	0.03	7-75	1" dia disc	2 π off-axis illumination with platinum reference, sample emission
Paraboloid	2-75	0.005	0.05	17	1" dia disc	2 π - steradian illumination, chopped source, large optics
Ellipsoid	2.5-80	0.01	0.02	5-79	1" dia disc	2 π illumination, no reference temperature and angle high cost, slow
Specular	2.5-50	0.01		10	dependent on optics	Relative to standard mirror, susceptible to scattering and polarization
Portable Emissometer (cooled thermopile)	0.5-22	0.015	0.05	0-70	1" dia or larger	Relative measurement subject to sample temperature
Emissometer (rotating source)	All	-	0.03	0-30	1" dia or larger	Relative measurement, sample temperature insensitive, large for hand operation

TABLE V TYPICAL ENVIRONMENTAL EXPOSURE TESTS

Property	Procedure	Test Conditions	Sample Configuration	Comments
Ultraviolet Degradation Laboratory	ASTM G26-70 Operating Light and Water Exposure Apparatus (xenon-arc Type for Exposure of Non-metallic Materials	See G27-70 for source operating procedure, temperature of 145°F	Compatible with mounting rack	Procedure for controlling exposure conditions. Correlation with natural exposure tests required.
	ASTM D2565-70 (similar to G26-70 for plastic materials	Temperature and irradiance monitored	Compatible with radiation beam size	Similar to G 26-70
Field	ASTM G7-69T Atmospheric Environmental Exposure Testing of Non-Metallic Materials	Exterior or storage environment on racks various exposure angle and temperature	Misc. to fit rack and compatible with shadowing.	Deterioration rated against a standard specimen.
	ASTM G24-73 Conducting Natural Light Exposures Under Glass	Specimen at least 76 mm behind window in cabinet	Same as G7-69T	Specimen exposed on clear days only (sunlight) or 24 hr day (Daylight)
Metallic Corrosion	ASTM D2570-73 Simulated Service Corrosion Testing of Engine Coolants or Standard TM-01-71 (NACE)	Temperature Cycle from 0 to 190°F	1/16 x 2 x 1 in. are standard	Prepared for automotive radiator applications
Material Compatibility	ASTM C590-69 Action on Substrates by coatings, adhesives, and Joint sealants used on or with Thermal Insulations	Immersion at 140°F for 7 days	1/2 x 3 in. (13 x 76 mm) or larger	Test conditions maybe more severe than field conditions. Results should be interpreted qualitatively
Temperature, humidity, etc.	ASTM-D638-72 Tensile Properties of Plastics	Depend upon required environment	compatible with test apparatus	Determination of influence of environment on structural properties

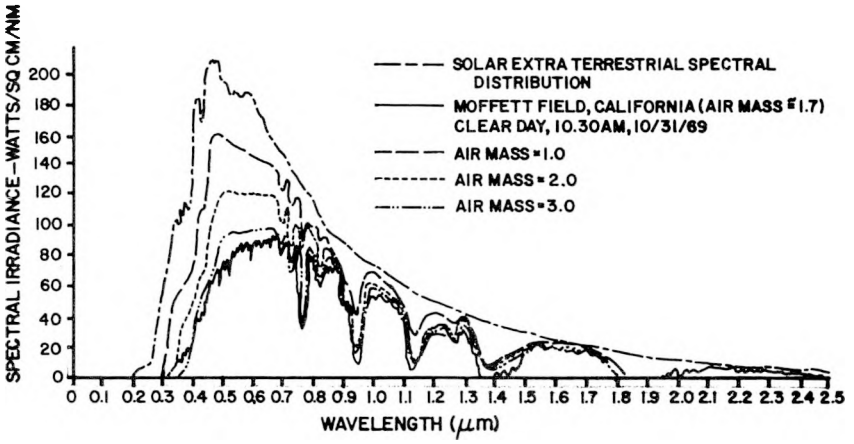


Fig. 1 — Comparison of Measured Air Mass ≈1.7 with Model Air-mass Spectral Distributions

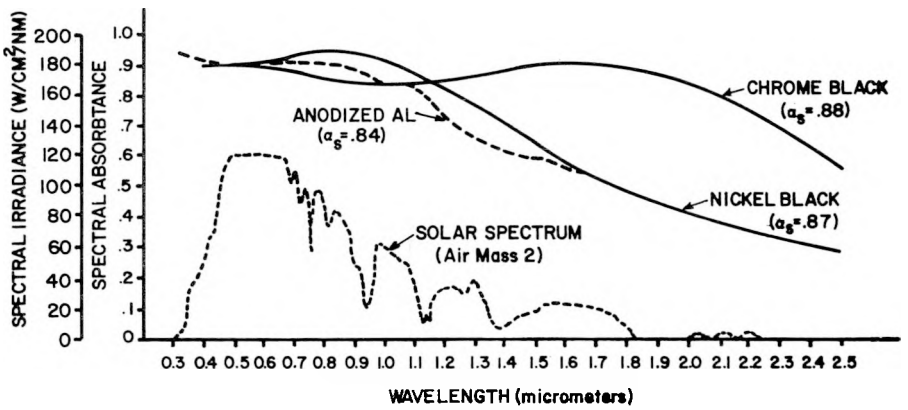


Fig. 2 — Selective Coating Solar Absorptance

Figure 3 **SPECTRAL HEMISPHERICAL TRANSMITTANCE**

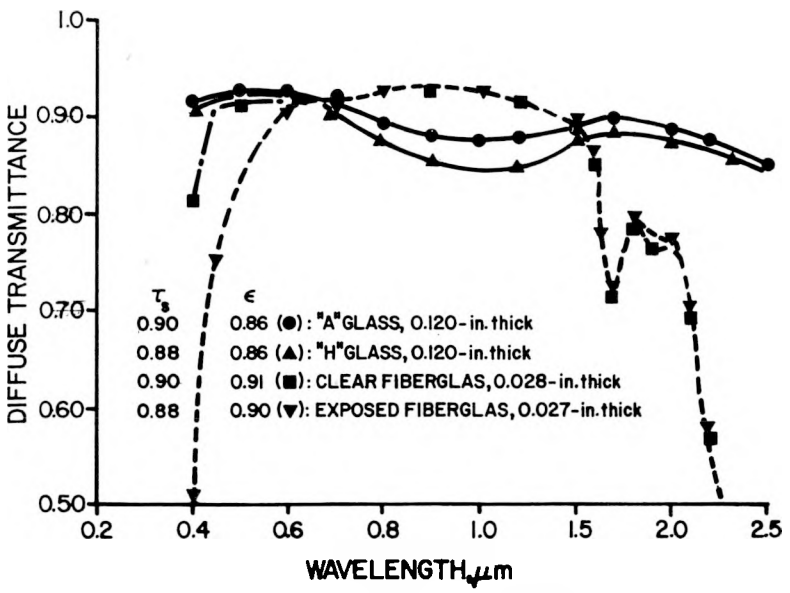


Fig. 3 — Spectral Hemispherical Transmittance for Selected Materials

DISCUSSION

Question (Forrest S. Higgs, A.I.A. Research Corporation): Your measurements standards seem to be organized around flat plate technology. If this is so, why?

Answer (Elmer R. Streed, National Bureau of Standards): Thermal conductivity measurements are performed with the conventional guarded-hot-plate apparatus. Optical property measurements utilize reflectance, absorptance, or calorimetric techniques. The spectral reflectance is preferred for solar absorptance because the influence of spectral distribution can be determined. The calorimetric method is preferred to determine total hemispherical emittance as a function of temperature utilizing spherical, cylindrical, or flat samples.

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DEVELOPMENT OF A PERFORMANCE SPECIFICATION FOR SOLAR COLLECTORS

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The development of a performance specification (spec.) for solar collectors was based on the need for a standard but flexible spec. that defined flat plate, liquid flow solar collectors by the major parameter affecting performance. Since solar collectors are a new piece of equipment, detailed specs. are necessary to describe collectors, to manufacturers and contractors who build and install them. As solar collectors are more widely available, collector specs. will be used by engineers and architects who normally specify equipment for buildings.

Dubin-Mindell-Bloome Associates originally wrote a performance spec. for the solar collectors to be used on a new Energy Conservation Demonstration, Federal Office Building in Manchester, New Hampshire. When ready for release, copies of this spec. may be obtained from: Construction Management Division, General Service Administration, Region 1 Post Office and Court House, Boston, Massachusetts 02009. In our other solar heating and cooling projects, a similar performance spec. will be used with modifications for different climates, improved collector designs and improved materials.

The basic areas covered in a performance spec. are thermal and mechanical. Thermal performance includes day-long heat collection BTU/ft^2 and instantenous efficiency (%). Mechancial performance includes materials, construction details and durability. Together these specify a state-of-the art collector that can be constructed in late 1975.

An important point is the difference between a performance spec. and a more common prescriptive spec. A performance spec. describes the results to be achieved, such as BTU's of heat to be collected. A prescriptive spec. describes the means to achieve desired results, such as a selective surface chemical composition. At this time a performance spec. is more useful because it allows freedom in design and stimulates innovation in a rapidly changing field. However, some items of the GSA spec. were described in a perscriptive manner for simplicity.

In researching criteria for the performance spec., a number of performance related factors were uncovered that have been little discussed at solar energy conferences or in papers. These include corrosion control, expansion of absorber plate and cover plates at stagnation conditions, freeze-up, moisture control, weather proofing, cover plate durability and day-long heat collection. All of these factors are realistic aspects of collector performance that must be addressed before a collector design can be approved.

An outline spec. is included with this summary to illustrate the general arrangement and main performance criteria. The spec. for GSA covered the same areas in more detail and included basic test procedures for evaluating thermal and mechanical performance.

OUTLINE PERFORMANCE SPECIFICATIONS FOR FLAT PLATE, LIQUID FLOW, SOLAR COLLECTOR

I. GENERAL - The collector shall be designed to absorb incoming solar radiation and transfer heat to a circulating fluid. The collector shall consist of cover plates, absorber plate, insulation and container, assembled in a manner to maintain thermal and mechanical performance over a 20 year service life.

II. THERMAL PERFORMANCE

1. Clear-day heat collection shall be 1,075 BTU/NET sq. ft. at the following conditions: outlet temperature = 120°F. inlet-outlet temperature difference = 40°, flow rate-variable, day-long isolation on collector plane = 2,150 BTU/sq. ft., optimum fixed tilt and Manchester, New Hampshire location.

2. Instantenous efficiency shall be 60% at the above conditions with insolation normal to collector = 300 BTU/hr/sq. ft.

III. MECHANICAL PERFORMANCE

1. Cover plates shall have a normal transmittance of 80% for all layers and transmittance at 60% incident angle of 70%. Cover plates shall be clamped and gasketed to container to prevent leakage of water or dirt. Spaces between cover plates shall be vented and have a desicant to absorb moisture. Cover plates shall not deteriorate under extended radiation, at stagnation temperatures, from hail or from wind loads.

2. The absorber plate shall consist of steel or copper flow passages fastened to or integral with, a flat steel, copper or aluminum plate. Flow passages shall be arranged for optimum heat transfer. Provision must be made for the venting and draining of flow passages. The absorber plate side facing the sun shall be coated with a selective surface of approximate absorptivity = .9 and emissivity = .15. The selective surface shall not deteriorate from radiation exposure, at stagnation temperatures, or from moisture normally present in the container. The heat transfer fluid shall be 50% water, 50% ethylene glycol. A corrosion control inhibitor shall be specified that

III. MECHANICAL PERFORMANCE (Continued)

2. will prevent failure of the absorber plate due to corrosion. Thermal expansion of the absorber plate shall not cause bukling or destructive stress.

3. The insulation shall consist of back and side insulation. The back insulation shall have a U=.075 and side insulation U=.3. The insulation shall not break down at the absorber plate stagnation temperature or 350^{o}, which ever is higher.

4. The container shall consist of an individual box or interated framework. It shall support the cover plate, absorber plate and insulation, and protect the components from the weather. The dimensions shall be approximately 4' - 0 x 8' - 0 x 0' - 6. The container shall have tabs in each corner or an equivalent method for attaching collector to support structure. Provision shall be made for venting, moisture removal, and thermal expansion.

IV. OTHER

1. The collector shall be guaranteed for one year.

2. The collector shall be packaged to prevent damage during shipping.

3. Provision shall be made for servicing an individual collector module either by removing cover plates or by removing an entire module, without disassembling an entire array.

4. The collector shall meet all applicable safety and construction codes.

5. Installation and operation instructions shall be furnished with the collector.

DISCUSSION

Comment (Hoyt C. Hottel, Massachusetts Institute of Technology): May I suggest that the appropriation of the term "stagnation temperature" to describe no-output collector temperature offends engineers competent in fluid mechanics and thermodynamics, since the term has a very precise and quite different meaning in those fields. They got there first. Don't confuse the novice by misuse of a term for which the term "no net output temperature" is available.

Reply (David L. Hartman, Dubin-Mindell-Bloome Associates): I agree that "stagnation temperature" would be more properly designated as "no net output temperature," or a similar term, when describing a situation of no fluid flow and high solar radiation impinging on a collector. This term, along with a number of others, should be standardized to facilitate communication in the solar field.

Question (William Beckman, University of Wisconsin): Since you propose performance specifications, why do you also propose property specifications, i.e., IR emittance and solar absorptance? It seems to me that these two different specifications may not be compatible.

Question (Herman G. Barkmann, Barkmann Engineering): Why specify prescriptive, i.e., transmissivity, angles, as well as performance—power and efficiency?

Answer (to both preceding questions): When writing the GSA collector performance specification, we found that certain items could be specified more simply and briefly in a prescriptive manner. Also, for certain items there was a redundancy, and the two techniques were used to obtain the same desired end result. However, as long as a given performance criteria item (i.e., day-long heat collection) can be met, a prescriptive criteria item (i.e., absorptivity) can be modified.

Question (Jagdish N. Prasad, Syska & Hennessy, Inc.): In your specification of solar collectors, did you take care of corrosion problems? What were the materials specified for absorber plates and tubings?

Answer: Corrosion control was covered in the GSA specification by requiring that the contractor engage the services of an approved water-treatment specialist. The specialist must prove the corrosion control effectiveness by suitable accelerated life tests, the goal being to prevent degradation of the absorber plate over the 20-year service lifetime.

Question (Unidentified): You specified an alpha-to-epsilon ratio of 0.9 to 0.15. It is generally accepted that absorption is much more important than emissivity. Would you accept an absorption of 99 percent at normal incidence and with improved performance at other angles of incidence?

Answer: Different absorptivities and emissivities would be accepted as long as the day-long heat collection criteria can be met.

start here 52/118

SOLAR COLLECTOR TESTING BY CALORIMETRY

By

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Cambridge, Massachusetts 02140

A new approach to collector testing was sought at Arthur D. Little early in 1974. The purpose of the program was to develop a simple solar collector test. With the appropriate test procedure it was felt that costly instrumentation and difficulties experienced with conventional techniques (e.g., N.B.S. Procedures, using the flow rate and temperature rise across the collector) could be avoided. One inherent problem with the standard flow rate, ΔT, measurement is the difficulty of maintaining steady test conditions so that reliable data may be extracted. In addition, the measurement of collector performance based on instantaneous collector efficiency as in the NBS collector testing standards, could be complemented by a system which could provide integrated collector efficiency based on daily averages. After a careful screening of the possible approaches, it was decided to explore a collector test based on calorimeter techniques.

The calorimeter principle differs from the standard collector testing approach because included in the thermal system is a large heat capacity element. In the case of a liquid collector, a water storage tank well insulated from the environment is used as seen in Figure 1B. The conventional system is based on the first law of thermodynamics for an open system using flow rates and ΔT measurements for calculation of the heat pickup of the collector as shown in Figure 1A. The calorimeter principle is based on a closed system in which the heat from the collector is stored in a large volume of water and the time rate of change of the temperature in the tank is measured for the heat rate pickup of the collector as expressed in the system governing equations in Figures 1A and 1B.

The advantage of the calorimeter is that only one variable need be measured, namely the storage tank temperature. This compares with the need for measuring both the flow through the collector and the temperature rise across the collector for the standard technique. The large liquid storage of the calorimeter also offers intrinsic thermal dampening, minimizes flow transients and stabilizes the operating temperature of the collector. Furthermore, with a suitably sized storage tank, measurements of the integrated heat pickup of the collector based on daily averages can be made easily.

The measurement of instantaneous heat rate delivery by the collector is accomplished by a real time differentiator giving the time rate of change of temperature in the liquid storage tank. The approximation to steady state conditions during this procedure is actually quite good, though it is recognized that the collector is really never at absolute steady state. This is because the calorimeter is based on a time rate of change of the collector and storage temperature.

As noted by Klein, Duffie, and Beckman in their ASME Paper No. 73-WA/SOL-1, the deviation from actual steady state performance of a solar collector is governed by the effective time constant of the solar collector. A transient error may then arise as a result of two effects: the storage effect of the collector, and the transient error of the system. The storage effect of the collector can be an error in the calorimeter technique if its heat capacity is not added into the total heat capacity of the storage tank system. Normally, lumped heat capacities of solar collectors range between .4 and 1.5 Btu's/sq ft - °F.* The lumped heat capacity of the storage tank based on one gallon of water per square foot of collector is of the order of 8.3 Btu's per °F per sq ft of collector. Therefore in a typical test between 5 and 15% added heat capacity due to the collector itself must be accounted for in the data reduction. A second consideration which arises from the use of calorimetry for the measurement of instantaneous solar collector efficiency is the transient error resulting from the dynamic response of the collector to the slowly varying system temperature necessary to the calorimeter function. This transient error can be viewed as a result of the lag of thermal elements in the solar collector. This means that the glass plate temperature of a collector under test might be slightly out of phase with the steady state values which would correspond to the existing instantaneous collector plate temperature, creating a so-called transient error deviation from the steady state performance of the collector. As will be discussed in a later paper+ the transient error for most collectors of sufficient storage quantity is extremely small and well within the acceptable accuracy of the test device, as to be neglected.

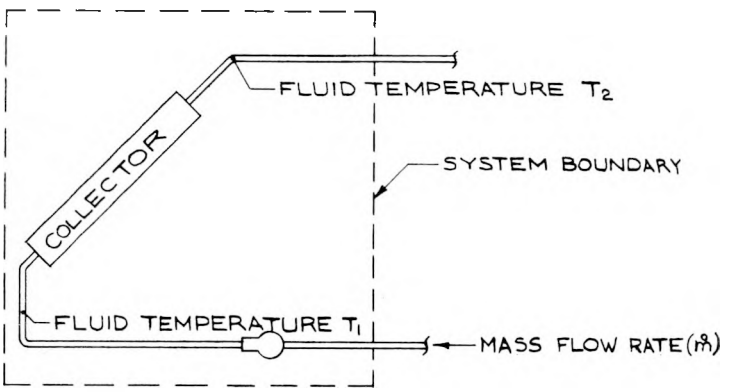
Experience with the calorimeter indicates that an instrumentation accuracy of about +2 and -7% can be expected under normal operating conditions. The major part of this error is in the actual measurement of the time rate of change of temperatures since fairly inexpensive solid state devices are used to provide the differentiation. The calorimeter is shown in Figure 2.

During a typical test of a solar collector, when it is desired to measure the collector performance over a wide range of operating temperatures in a single day, the calorimeter can be used without the heat rejection capability. In this mode of operation the calorimeter is operated as shown in Figure 1B. The initial storage tank temperature starts low and rises

*Klein, Duffie, Beckman, "Transient Consideration of Flat Plate Solar Collectors" ASME Paper 73-WA/SOL-1, Dec. 17, 1973.

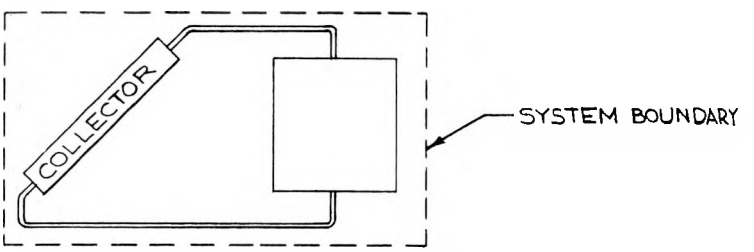
+Paper on Calorimeter theory and practice to be submitted to Solar Energy Journal.

throughout the day until the test is terminated. During the test instantaneous heat pickup is measured as shown in the actual test data in Figure 3. The heat rate pickup is shown on the left while the instantaneous solar radiation as measured by a Sol-A-Meter pyranometer is on the right. As indicated before, the system temperature is increasing throughout the day and as seen in the test data, the heat rate pickup of the collector departs from the increasing solar radiation curve later in the day as the higher collector operating temperatures result in increased thermal losses. During a single day's test such as this, nearly 50 data points were developed for water temperatures of 110°F to 180°F. Some of the data points are graphed on a collector efficiency plot in Figure 4. The data here is compared with predicted steady state performance based on collector design parameters and predicted on the Arthur D. Little computer program. The good agreement between predicted and measured performance of the collector indicates that the approximation of steady state collector operation is reasonable and that the Calorimeter provides a great deal of collector data in a small amount of time.



GOVERNING EQUATION: $\dot{Q} = \dot{m} C_p (T_2 - T_1)$
WHERE $\dot{Q}$ = HEAT DELIVERED BY COLLECTOR,
C_p = WATER HEAT CAPACITY

Fig. 1A — Open System—Standard



GOVERNING EQUATION: $\dot{Q} = mC_p \frac{dT}{d\theta}$
WHERE m = TOTAL SYSTEM MASS,
$\frac{dT}{d\theta}$ = TIME RATE OF CHANGE OF TEMPERATURE

Fig. 1B — Closed System—Calorimeter

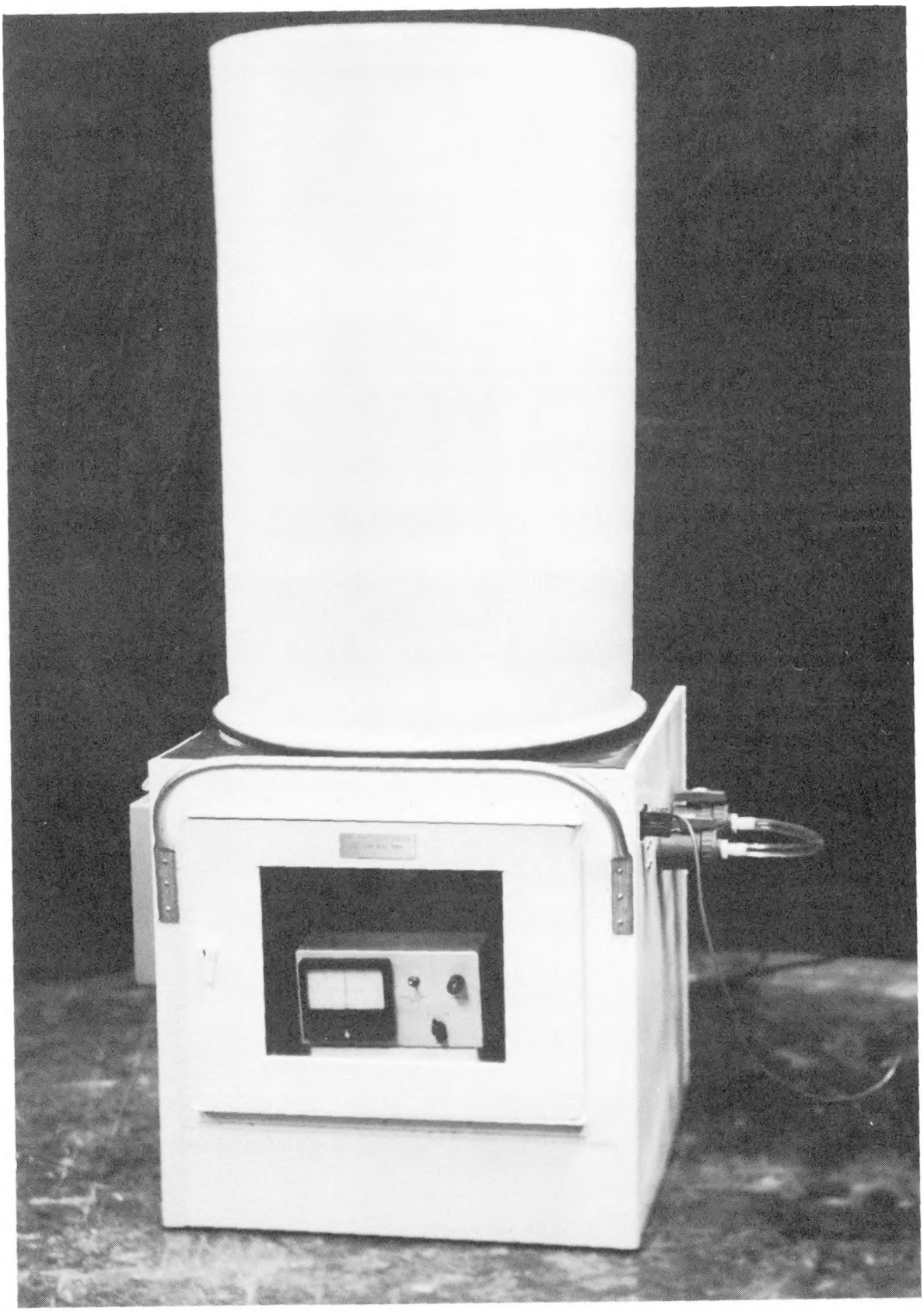


Fig. 2 – Calorimeter for Solar Collector Test

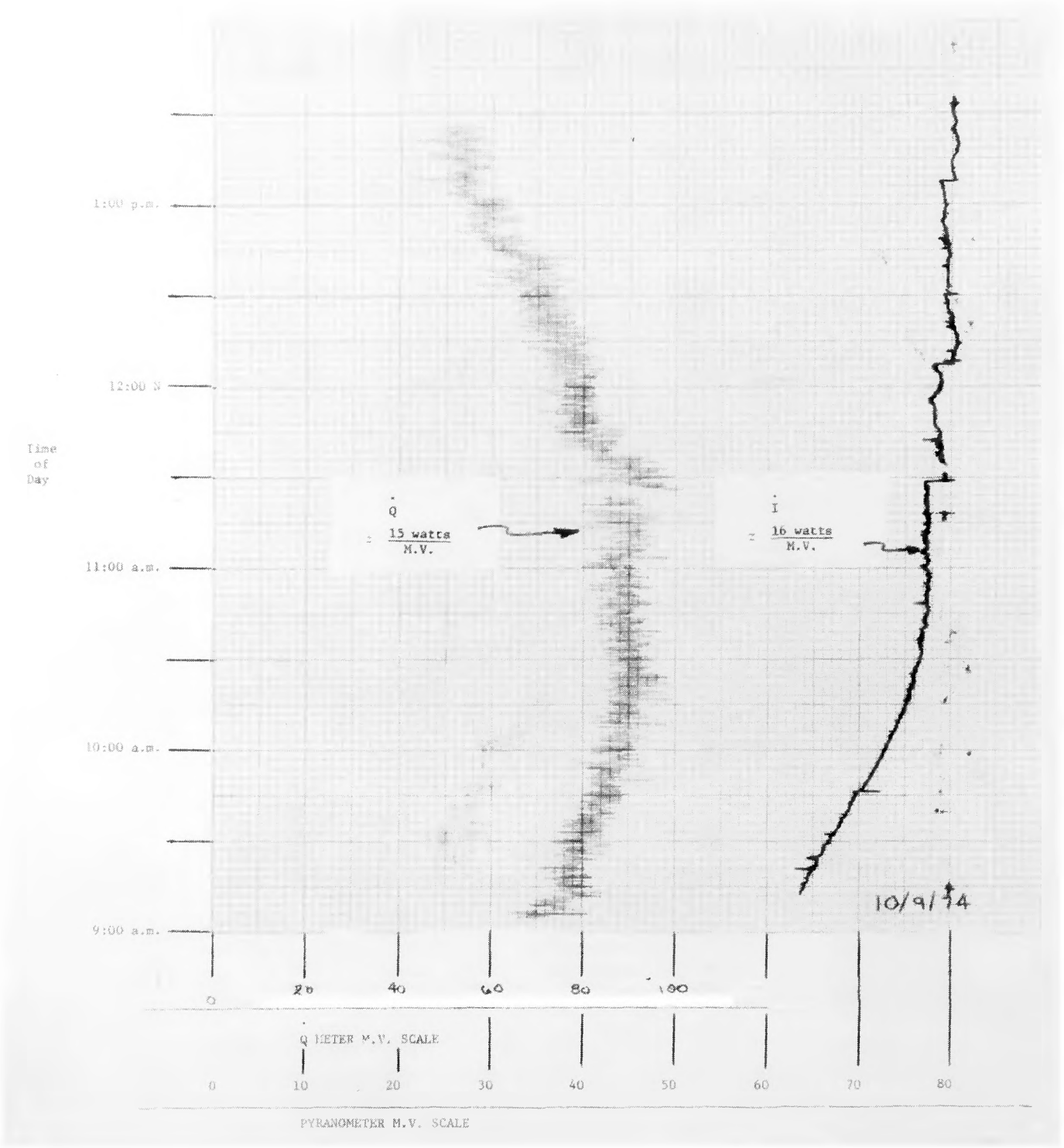


Fig. 3 — Test Data From Calorimeter

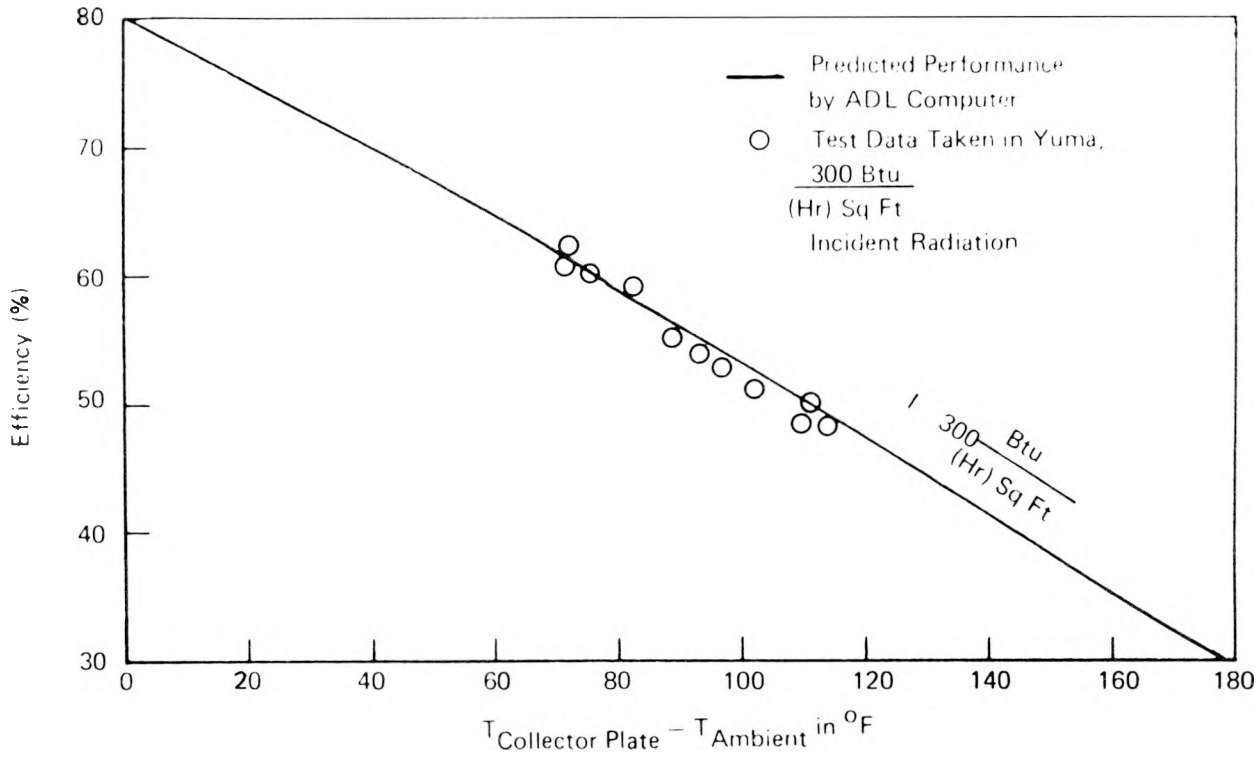


Fig. 4 -- Collector Test Data Taken in Yuma, Ariz.

DISCUSSION

Question (John C. Ward, Colorado State University): How does one evaluate an air solar collector by calorimetry?

Answer (David Lee, A. D. Little, Inc.): The principle of calorimetry is universally applicable to liquid and air collectors alike. To use a calorimeter with an air collector, the time rate of change of a temperature of *suitable* storage media would be measured. We have not tried calorimetry with air; however, I would think that the mixing requirement to attain uniform temperature in the storage media might be a severe problem.

Question (Gary Brockett, International Heating and Air Conditioning Division): Using the calorimeter method you described, you mentioned a 15-gal-capacity test stand. Are you not penalizing the large capacity units by a rapid increase in calorimeter temperature? This method does not seem to offer a direct comparison between panels.

Answer: We adjust the calorimeter capacity to provide about 1 gal of storage per square foot of collector. For collector units measuring 30 or 40 ft^2 of frontal area, a larger calorimeter storage would be necessary.

Question (Robert L. San Martin, New Mexico State University): What percentage of the total energy collected in the storage tank is developed by the "fast" stirring device?

Answer: A negligible amount of energy is added by stirring as determined in controlled laboratory tests.

Comment: (Hoyt C. Hottel, Massachusetts Institute of Technology): "Flow calorimeters" need a mixing box on the oulet to guarantee a proper measurement of temperature rise. Layering in tanks makes their temperature rise far more questionable. A warmed stream returning to a tank tends to flow to the top. Doesn't this make you uneasy about interpretation of space-mean tank temperature? If 5 percent accuracy is acceptable, I mostly withdraw objection.

Reply: Quite true, maintaining a uniformly mixed tank is difficult. The stirrer is designed to create substantial turbulence, and the warm inlet is at the bottom and the drawoff is at the tank bottom, to induce thermal convection. Small temperature variations do exist, however, and are of the order of 0.2° to 0.5° F. These variations would be very difficult to eliminate if it were necessary to do so. The calibration of the calorimeter, being performed under the same conditions as a collector test (constant stirring speed and guarded heat shield surrounding the tank), automatically takes into account the variations. The reported accuracy is 5 percent, based on laboratory test.

Comment (Jan F. Kreider, Environmental Consulting Services): Your test procedure is less widely applicable than is the National Bureau of Standards procedure as a result of the more complex and less durable components. Differentiators, for example, are notoriously noisy and drift prone. Please comment.

Reply: We essentially use a capacitor feedback such that the resultant break point is substantially above the measured frequency, and all higher noise (above 50 Hz) is damped out. This, along with the low-drift (0.6μ V/C voltage drift), inexpensive operational amplifiers, managed the noise and drift.

Comment (Benicio I. Dussan V, Philadelphia, Pa.): The statement that the efficiency of the solar collector is independent of the water flow needs to be clarified. Not much was said about the thermal inertia of the system and the variations in the temperature field of the water body, as related to near-instant determination of the collector's efficiency, particularly in most transient periods.

Reply: The heat collection *measurement* is independent of flow rate, since it is based on the total heat capacity of the system. There was no mention in the paper of the effect of flow rate on collector efficiency. The calorimeter principle permits the evaluation of collector efficiency without measuring flow rate, but it makes no assumptions about flow rate and collector efficiency.

With regard to thermal inertia effects, the stored water mass used for calorimetry is rapidly stirred to minimize temperature gradients. The principle of the calorimeter is, of course, to measure the time rate of change of temperature of the thermal mass by means of a very sensitive differentiator that can determine a few hundredths of a degree change per minute. The only transient measurement error of the heat rate pickup is in the electronic damping to eliminate unwanted noise, and this is a small error. The "temperature variations" referred to in the question are in fact the temperature rates of change, and we have taken great pains to measure them.

SESSION 8

SOLAR ENERGY PROGRAMS OF THE DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT AND THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The joint presentation by Mr. Sherman and Mr. Scott was a status report on the Program Plan for the Solar Heating and Cooling Demonstration Act. Because the National Program Plan for Solar Heating and Cooling of Buildings has since been published by the Energy Research and Development Administration, the written summary of their remarks and the discussion that followed are not included in the Proceedings.

The presentation by Mr. Ragsdale was an overview of the solar energy activities at the NASA Lewis Research Center, indicating how these projects interface with other NASA solar energy activities. Because the projects were covered in more detail in the following presentations, the written summary of Mr. Ragsdale's presentation and the discussion have not been included in the Proceedings.

SUMMARY OF NASA-MARSHALL RESIDENTIAL SOLAR COLLECTOR EXPERIMENTS

Joseph R. Dabbs
Program Development Directorate
Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

We at NASA and the Marshall Space Flight Center (MSFC) are pleased to have this opportunity to describe the activities of the Marshall Space Flight Center in demonstrating the utilization of Solar Energy for residential and commercial heating and cooling. The engineering demonstration at MSFC of the solar powered heating and cooling system has been placed in full operation since May of 1974.

The demonstration house as seen in Fig. 1 actually consists of three surplus office trailers fitted with a free standing roof for minimum cost and construction time. Actual construction started in August 1973, concurrently with early solar collector testing.

The technology base for the current MSFC solar collector activities is primarily in high performance materials (e.g., thermal coating, thermal storage, and transparent cover materials), and in analytical or computer thermal simulation of spacecraft. For example, the solar absorptive coating developed by MSFC and used in place of black paint now permits collector operation at temperatures high enough to efficiently operate modified commercial gas-fired air conditioners. The development and environmental evaluation of this stable coating has utilized space related tools, techniques, and facilities as well as the experience and training of MSFC's personnel. The computer simulation techniques now used to predict solar house heating and cooling performance for different geographical locations and environmental conditions are based on the same techniques used in successfully simulating and predicting spacecraft conditions such as those encountered in the recent Skylab missions. These computer tools permit rapid and extensive evaluation and minimize time consuming experiments and demonstrations.

The schematic of the house as seen in Figure 3 is shown for basic familiarization of the viewer. In general, the collector flow pump is turned on when collector temperature exceeds storage fluid temp. The collector pump is turned off, and collectors drained of fluid, when collector temp. falls below storage tank temperature.

The solar collector is one of the key technology and cost elements in economic utilization of solar energy. Previous materials have placed

limits on both the minimum cost and technical performance of this key element. MSFC attempted to provide alternates to these limitations primarily through use of a better transparent cover than glass and a better absorptive coating. The coating's superior performance characteristics come from an electroplated black nickel/bright nickel coating and was previously developed for spacecraft use. The coating has the same high absorptivity as black paint type coatings; however, it loses very little radiated heat back to the atmosphere, thus reducing heat loss and increasing efficiency. This coating process was used to coat over 300 2' x 3' panels in Marshall's shops with very good repeatability of performance as indicated by test data summarized in Figure 5. Since this coating was developed by the government, the United Stated and international patent rights are secured, and it is freely available to the Nation.

The solar collector module design that is currently being used on the demonstration roof was not fully optimized for technical performance but was designed for a quick initial demonstration to acquire engineering data. In the MSFC design, the transparent cover is a composite of Tedlar clear plastic film bonded to commercially available welded wire mesh fencing. Tedlar has the best known outdoor life characteristics of any plastic film, has been extensively used for outdoor signs, and has been used experimentally for greenhouses. The manufacturer has developed a special type and thickness of Tedlar for use in the MSFC developed wire and Tedlar composite. Tests with the composite and previous manufacturer's tests indicate the possibility of lifetimes in excess of ten years. The composite has essentially the same high solar transmission as glass, yet is cheaper, lighter and far less sensitive to hail damage. The collector panels are 2' x 3' aluminum roll-bond panels with integral fluid passages and coated with the high absorptivity coating. The individual panels are coated with the special plating and are then manifolded and placed in an aluminum tray with fiberglass insulation to prevent heat loss. Seven of the individual panels are connected together to produce a module 2' wide by 21' long which is assembled and completely checked out during manufacturing process. Thirty-one of these modules are then installed on the roof to form the 1300 ft^2 collector.

Since collector performance was the most critical element in the system design, a prototype (2' x 21') module was fabricated and placed in an inclined position simulating the roof installation. Figure 7 is a photograph of this test showing the trailer and roof construction in the background. The test module was installed last December and extensive thermal and fluid flow tests were performed. The test module was exposed to the weather at all times to understand the effects of dust, dew, rain, etc.

In addition to extensive rain in this period, two hailstorms passed over the test site. The test performance confirmed all analytical predictions. Some evidence of deterioration or damage is now evident with the thin (2 mil) Tedlar and wire outer cover. However, the collectors with 4 mil Tedlar have experienced no problems. At this time it is believed that the problems are more associated with design and fabrication rather than basic Tedlar properties and characteristics.

Some representative test data of the two different panel designs is given in Figures 8, 9, and 10.

One additional system improvement has been achieved in lowering the inlet water temperature requirement of the modified ARK-LA absorption cycle air conditioners from 210°F to 190°F with significant improvements in the systems Coefficient of Performance (COP).

Follow-on activities include the development of cost effective collector designs using industry experience in conjunction with MSFC technology. The emphasis is upon developing technically adequate collector designs which industry can fabricate and market there by leading to commercial availability of solar heating and cooling systems.

This concludes the summary of the current MSFC solar collector efforts and some of our immediately planned follow-on activities. Our future activities attempt to utilize and combine the unique and existing experience, and capabilities of NASA-MSFC and industry. We believe the program has made, and will continue to make, significant contribution to the utilization of solar energy.



Fig. 1 — Demonstration House

MSFC EXPERIMENTAL SOLAR HOUSE

DEVELOPED AND BUILT AUGUST 1973-JUNE 1974

PURPOSE

TO PROVIDE AN ENGINEERING TEST BED FOR EVALUATION OF CURRENT AND IMPROVED RESIDENTIAL HEATING AND COOLING SYSTEMS.

PRESENT ACTIVITIES

- DATA RECORDING
- DESIGN IMPROVEMENTS
- ENGINEERING EFFORTS TOWARD LOW COST

SPECIFICATIONS

LIVING AREA

1507 SQ. FT. (HEATING/COOLING REQUIRMENTS EQUIVALENT TO RESIDENTIAL 2500 SQ. FT. HOUSE)

HEATING/COOLING SYSTEM

COLLECTOR AREA	1300 FT. 2
HEATING CAPACITY	70 000 BTU/HR.
COOLING CAPACITY	36 000 BTU/HR. (3 TON)

Fig. 2 – MSFC Solar House Data

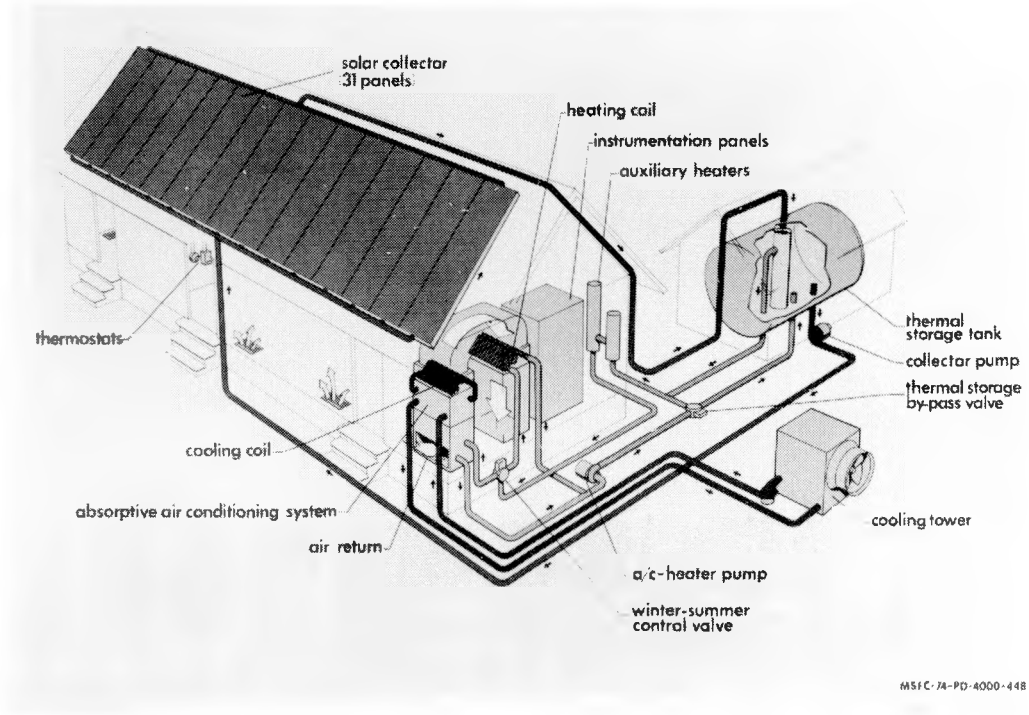


Fig. 3 – MSFC Solar-Powered Residential Heating and Cooling System

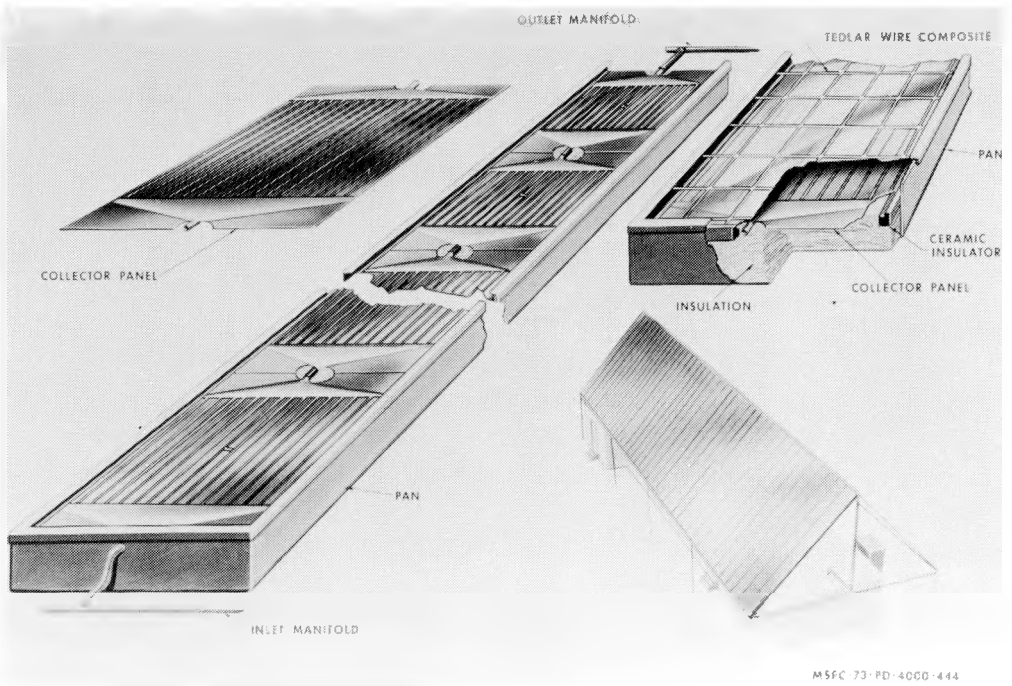


Fig. 4 – MSFC Collector Design Features

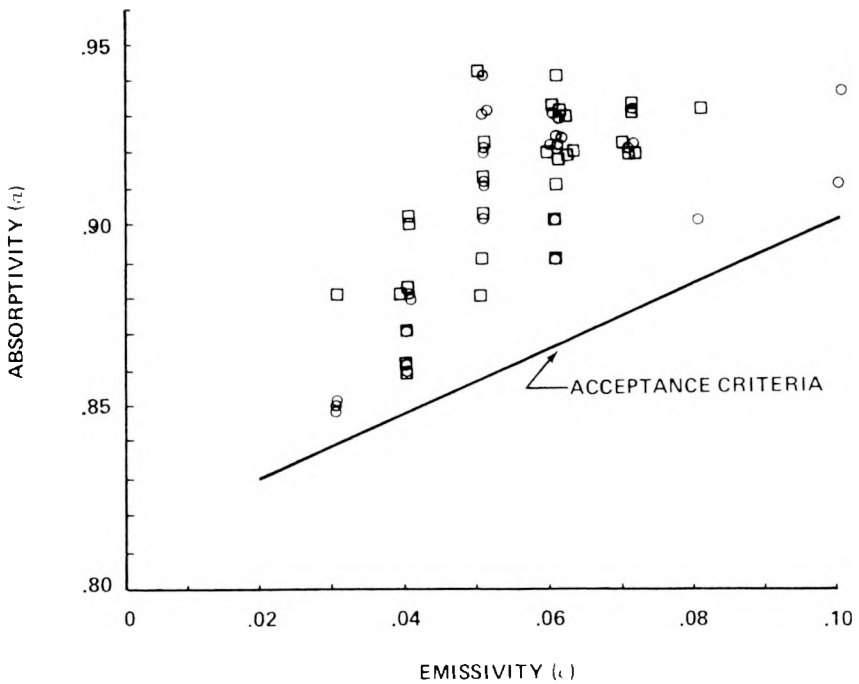


Fig. 5 – Test Data, Absorptivity and Emissivity Readings
(Marshall Space Flight Center, MSFC Solar Power
Residential Heating and Cooling Project)

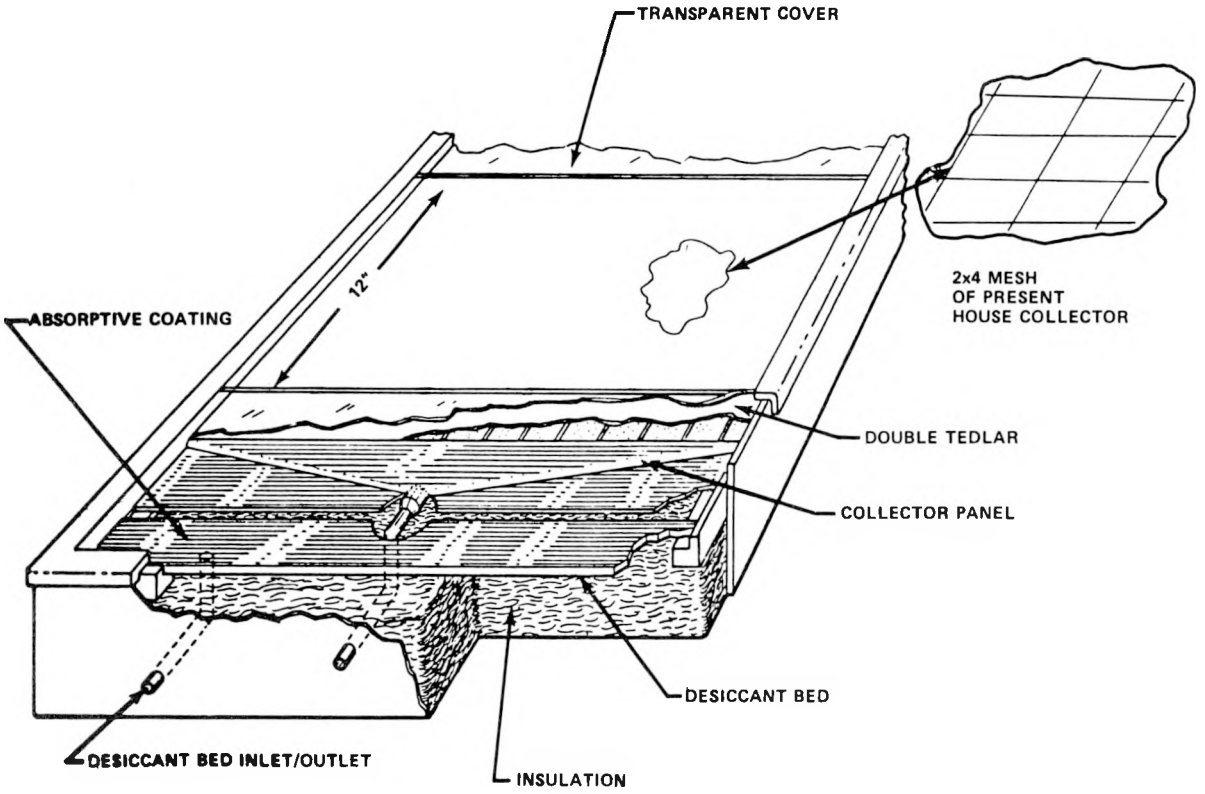


Fig. 6 – Flat Plate Solar Collector



Fig. 7 – Collector Performance Test with Prototype
(2-ft by 21-ft) Module

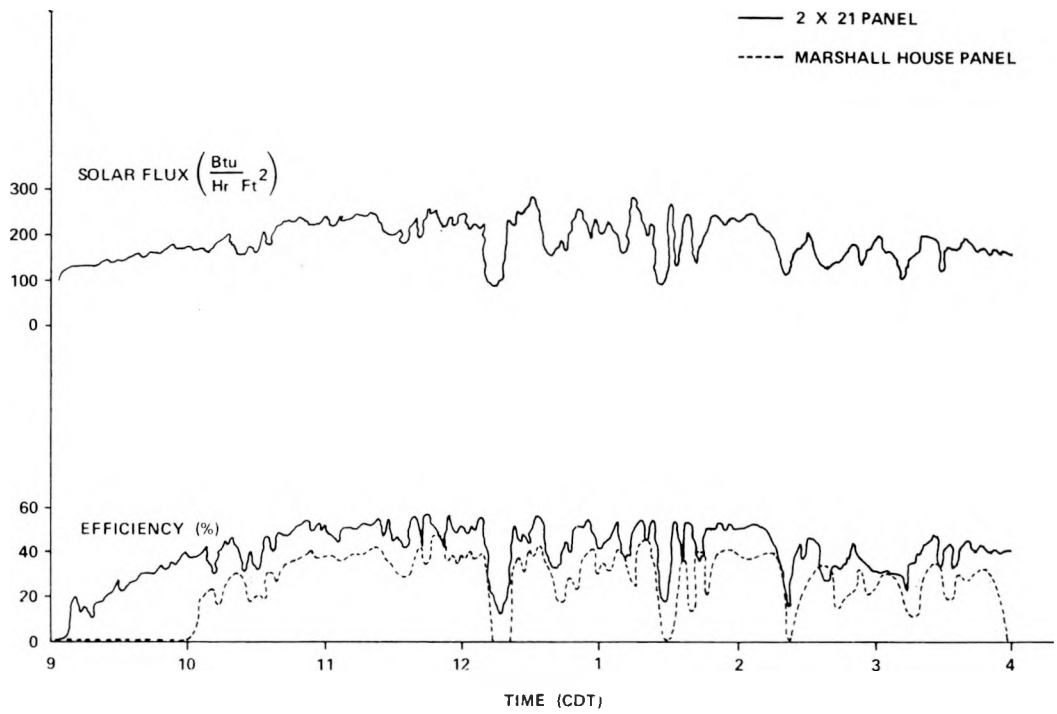


Fig. 8 – Panel Operation Time

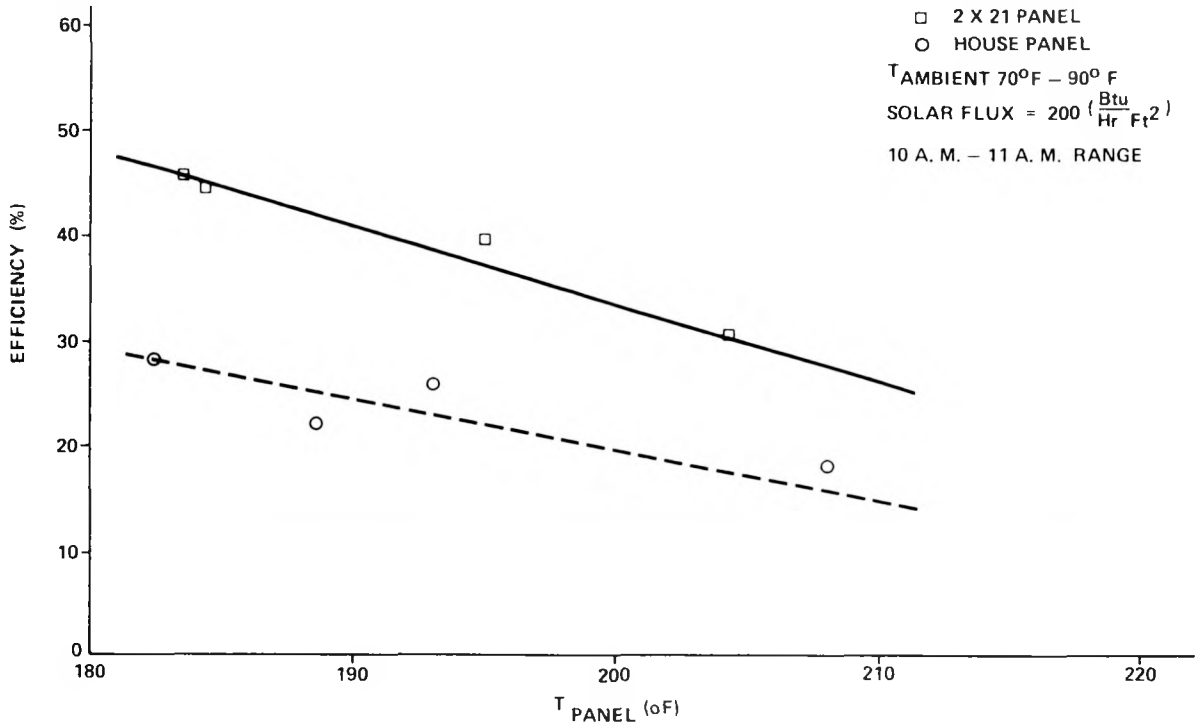


Fig. 9 – Efficiency Comparison

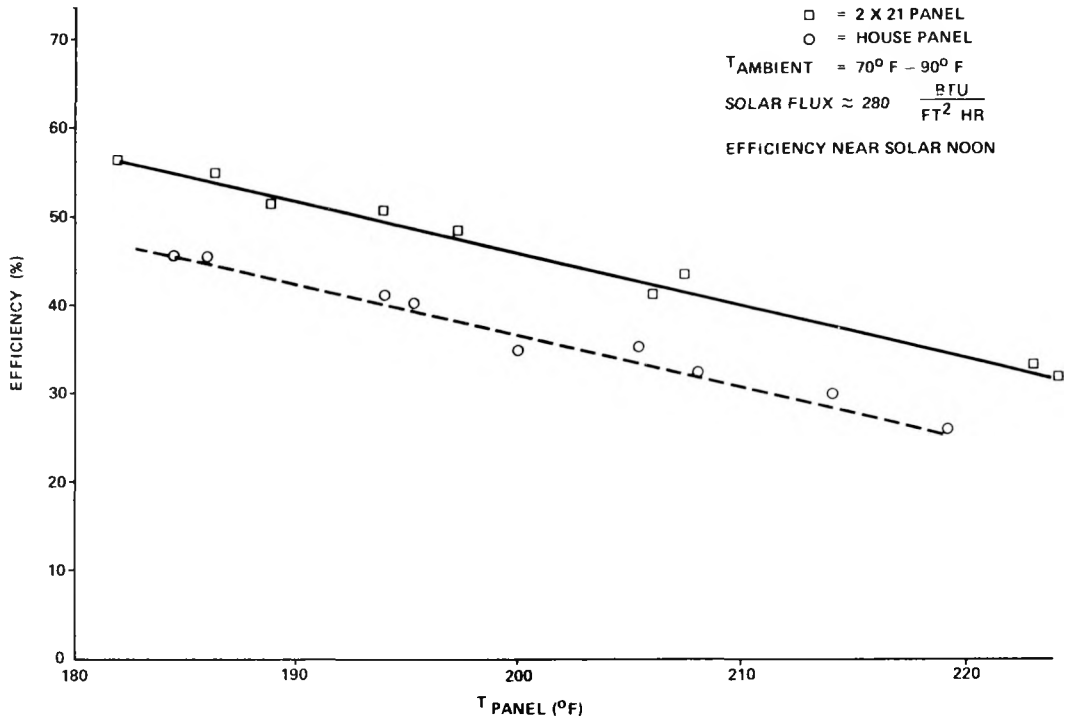


Fig. 10 – Efficiency Comparison

DISCUSSION

Question (Lynn D. Russell, University of Tennessee): Would you comment on the steps required to convert the absorption air conditioning system from operation on gas to use of solar energy? What about any stability problems encountered? How does its C.O.P. vary with temperature variations of the heat source?

Answer (Joseph R. Dabbs, NASA Marshall Space Flight Center): The primary modification to the ARKLA unit was replacement of the gas burner assembly with a hot water heat exchanger. Regarding the actual performance of the unit, an MSFC report is being prepared for release in the near future that will discuss this in some detail.

Question (Richard R. Lewchuck, PPG Industries): What is the current status of the awarding of the RFP relative to the MSFC solar facility, i.e., cost-effective solar collector design?

Answer: Those contracts were finally let early this year.

Question (Richard Brecher, Energy Utilization Systems): How may published work at NASA Marshall be obtained?

Answer: All MSFC published works are listed in the semimonthly abstract journal, *Scientific and Technical Aerospace Reports* (*STAR*), which is sent to many organizations and institutions on a subscription basis. In addition, special energy bibliographics have been prepared. For more general information, contact the Technical Utilization office, Marshall Space Flight Center, Alabama 35812.

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STATUS OF THE NASA-LEWIS FLAT-PLATE COLLECTOR TESTS WITH A SOLAR SIMULATOR

By

F. F. Simon

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

INTRODUCTION

The approach being taken at the Lewis Research Center for determining collector performance is to test collectors under simulated (indoor) and actual (outdoor) conditions. This paper reports the results to date of the collectors tested at Lewis under simulated sun conditions. The initial results reported in reference 1 are included herein as part of the status report.

EXPERIMENTAL FACILITY - SOLAR SIMULATOR

The basic rationale for the use of a solar simulator for the testing of solar collectors was given in reference 2. This approach allows for controlled conditions that make it possible to properly compare the performance of different collector types. The simulator is shown in figure 1. For more details on the simulator and its operation, the reader is referred to references 1-4.

COLLECTOR TEST RESULTS AND DISCUSSION

The experimental efficiency of each collector was calculated using the following equation:

$$\eta = GC_p(T_0 - T_1)/q_i \qquad (1)$$

The efficiency determined for a constant flow rate of 10 lb/hr ft^2 was plotted versus the temperature difference to heat flux ratio for an inlet temperature ranging between 75°-210°F, a simulated heat flux ranging between 150-340 Btu/hr-ft^2, wind speed of 7 mi/hr and an ambient temperature ranging between 75°F in winter to 85° in summer.

Correlation Method

Justification for the method of correlating collector test data was presented in reference 2. Basically the method involves the

utilization of the analytical equations that describe collector performance. The three equations useful for obtaining key collector parameters are as follows:

$$\eta = \alpha\tau - U_L(\bar{T}_P - T_a)/q_i \quad (2)$$

$$\eta = F'\left[\alpha\tau - U_L(\bar{T}_f - T_a)/q_i\right] \quad (3)$$

$$\eta = F_R\left[\alpha\tau - U_L(T_1 - T_a)/q_i\right] \quad (4)$$

Examples of how these equations can be used in conjunction with the experimental data were given in references 2 and 4. Performance curves of a black nickel two-glass collector from reference 4 are shown in figures 2a, 2b and 2c. From an inspection of equations 2-4, it can be seen that by plotting efficiency versus temperature difference divided by radiant flux (η vs. $(T-T_a)/q$) as indicated in figure 2, it is possible to obtain key collector parameters from the slope and intercept of the correlating lines. As explained in reference 2, the values of $\alpha\tau$, U_L, F' and F_R obtained in the above manner will give specific information on why a collector excelled or why it performed poorly

Collector Efficiency Curves

The efficiency in terms of the inlet temperature and radiant flux level for the fifteen collectors tested to date is shown in figure 3. The appearance of the curves of figure 3 points out the large differences that exist among the collectors tested. It is apparent that not any one collector design has the highest efficiency throughout the entire range of the parameter plotted on the abscissa.

This is due to two considerations in evaluating performande; considerations that are not always compatible. One consideration is the slope of the curves, which is a measure of the heat loss. It is seen from figure 3 that those collectors with a single cover have a larger slope and therefore a larger heat loss than those with two covers (e.g., No. 8 vs. No. 9). Larger heat losses are also found for coatings having higher emissivity values (flat black coatings as contrasted to selective surface coatings, No. 10 vs. No. 5). The second consideration is coating absorptivity (α) and cover transmittance (τ). Collectors with two covers while decreasing heat loss also lower the cover transmittance as compared to single cover collectors. For comparable absorptivity values the product of $\alpha\tau$ is lower for the two-cover collector compared to the single covered ones. This results in the two-cover collector having lower values of the performance curve intercept on the ordinate, and higher efficiencies at higher values of the abscissa due to lower heat losses. The single covered collectors are higher performers at lower inlet temperatures, but a cross over point is reached whereby at higher abscissa values the double-covered

collectors become better performers. This effect is seen in comparing No. 11 with No. 12, No. 2 with No. 4, and No. 10 with No. 13. If transmittance is comparable, the efficiency values at the intercept of figure 3 is directly related to the absorptivity of the surface. There will be further discussion on this point later in this report.

Collector Performance Ranking

From the performance curves of figure 3, collector efficiency may be determined for the different functions a collector might be required to perform. The different functions considered here for the purpose of performance ranking are: heating of swimming pools ($T_i = T_a = 80°F$), generation of hot water (T_i = 140 F, $T_a = 80°F$), heating ($T_i = 120°F$, $T_a = 0°F$), absorption A/C ($T_i = 200°F$, T_a - 80°F), and using the collector thermal output for running a solar Rankine machine ($T_i = 240°F$, $T_a = 80°F$). The resulting calculations using figure 3 are shown in Table I. All ambient temperatures are 80 F except for the heating case which is 0°F. This lower value of the ambient temperature introduces an error of approximately 8 percent in the calculation of performance because the performance curves of figure 3 were obtained at a higher ambient temperature. This error does not change the order of performance ranking for heating, and is therefore not important in the present discussion.

Table Ia shows, as expected, that in the case of pool heating, a simple black-paint one-glass collector is best. It is clear that the addition of a honeycomb (collector 11) is only an added economic burden. It can probably be demonstrated that in some cases (e.g., no wind) it would be more cost effective to have no cover sheet for collectors which are to be used for pool heating.

If collector performance were the sole selection criterion for a collector that will produce hot water, then a honeycomb collector (collector 11, 12) or a selective two-glass collector (collector 7) would be chosen (Table Ib). However, on the basis of cost and practicality, it is believed that a black-paint two-glass collector (collectors 1, 13-15) is the best choice.

Since heating and air conditioning have essentially the same requirements as regards temperature difference ($T_i - T_a$), they are grouped together in Table Ic. The best performing collector for this type of duty is the black-Ni two-glass collector (collector 7). Close behind collector No. 7 is the flat black-paint honeycomb two-glass collector (No. 12). An additional factor to be considered for No. 12 collector is the transmission losses at other than normal incidence of solar flux due to the mylar honeycomb. A factor which is not generally being considered is the reliability (life) of the black-nickel selective coating. The reliability of such a coating needs proving out before collectors utilizing this coating may be considered dependable. The use of selective coatings to cut down radiation

losses becomes even more evident at the temperatures needed for solar Rankine system performance. This is clear in the performance ranking shown in Table Id. The efficiency levels of the better performing collectors for a Rankine system are the same as those of the A/C-heating case.

Collector Performance Parameters

Collector performance parameters of five collectors based on the correlations according to equations 2, 3 and 4 are shown in Table II. These collector parameters permit a determination of the "why" a collector performed the way it did. Collectors 7 and 13 are basically the same with exception of the coating used on the absorber plate. This basic sameness in construction is reflected in nearly the same values of F' and F_R and in equal values for the glass transmittance (τ). Since the absorptivity for the two collectors is identical, their difference in performance is attributable to the lower heat loss of the black-nickel collector. Comparing collector No. 7 with collector No. 9, it can be seen that the greatest single factor contributing to the latter's lower performance was the lower value of absorptivity.* Table II also demonstrates that the value of absorptivity determined from the intercept of curves such as that of figure 2a compares well with the determination of absorptivity from spectral reflectivity measurements.

SUMMARY OF RESULTS

Fifteen collector types have been given rankings based on their performance in the NASA-LeRC simulation facility. Performance rankings are based on the function a collector is expected to perform. The best performers in each category of pool heating, hot water, A/C and heating and solar Rankine are as follows:

A. Pool Heating

1. Black paint - one glass

B. Hot Water

1. Black paint plus honeycomb - one or two glass
2. Black nickel - two glass
3. Black paint - two glass

C. Absorption A/C or Heating

1. Black nickel - two glass
2. Black paint plus honeycomb - one or two glass

D. Solar Rankine

1. Black Nickel - two glass
2. Black paint plus honeycomb, two glass

*Had both collectors used coatings of equal absorptance, it is expected their performance would have been equal.

An evaluation of collector performance by an inspection of collector performance parameters indicated that simply reducing collector heat loss will not guarantee a good performing collector. Some collectors which used selective coatings to reduce radiation losses were found to have lower than expected performance due to a lower than desired value of absorptivity.

For any given application, the final collector selection should be determined from information on collector cost, collector reliability and collector performance based on all-day conditions.

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1. R. W. Vernon and F. F. Simon: Flat-Plate Collector Performance Determined Experimentally with a Solar Simulator. NASA TM X-71602, presented at U. S. Section Annual Meeting of Solar Energy Society, August 1975.

2. F. F. Simon and P. Harlamert: Flat-Plate Collector Performance Evaluation, The Case for a Solar Simulation Approach. NASA TM X-71427, 1973.

3. K. Yass and H. B. Curtis: Low-Cost Air Mass 2 Solar Simulator. NASA TM X-3059, 1973.

4. F. F. Simon: A Comparison Under a Simulated Sun of Two Black Nickel-Coated Flat-Plate Solar Collectors with a Nonselective Black Coated Collector. NASA TM X, 1975.

SYMBOLS

C_p	Fluid heat capacity, Btu/lb°F
F'	Collector plate efficiency factor, dimensionless
F_R	Collector plate heat-removal efficiency, dimensionless
G	Flow rate of collector fluid, lb/hr-sq ft of absorber surface
q_i	Incident direct solar radiation, Btu/hr-ft^2
$\overline{T}_f$	Av rage collector fluid temperature, °F
T_1	Fluid inlet temperature, °F
T_o	Fluid outlet temperature, °F
$\overline{T}_p$	Average collector plate temperature, °F

T_a Ambient temperature, °F

U_L Overall collector heat loss coefficient, Btu/hr-ft^2°F

α Collector surface absorptivity, dimensionless

η Collector efficiency, dimensionless

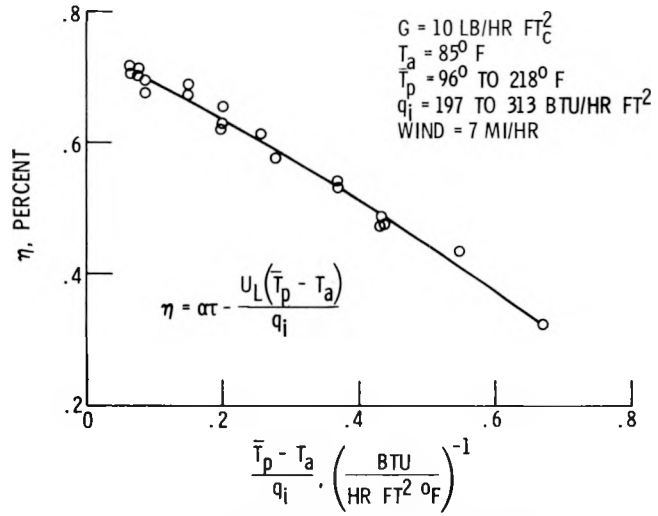
τ Effective transmittance

Superscripts

$\overline{\quad}$ Average conditions

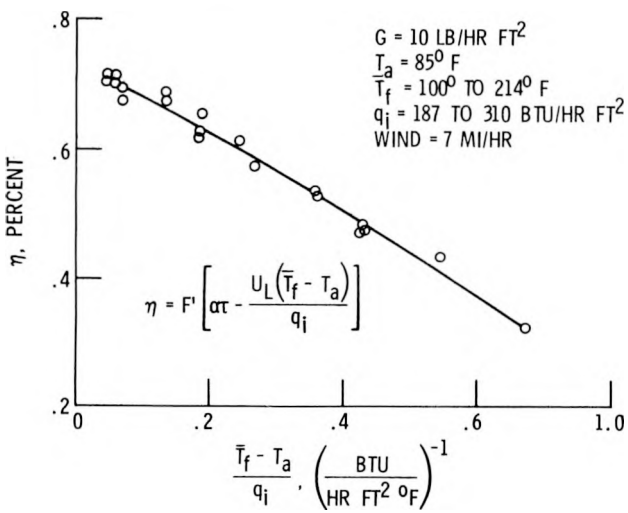


Fig. 1 – Indoor Facility Used to Experimentally Determine Solar Collector Performance



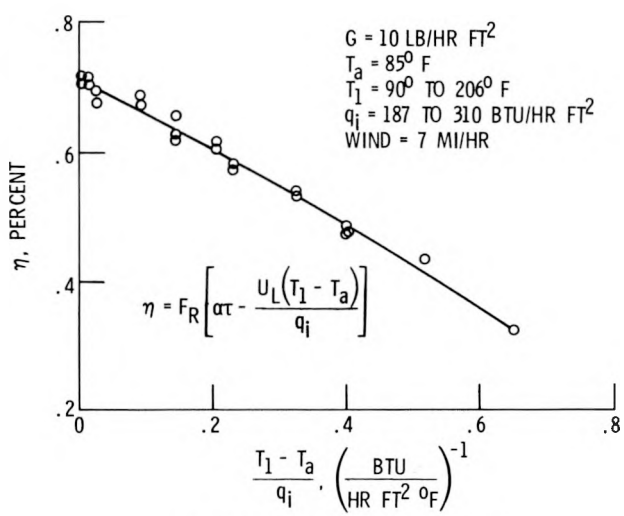
(A) HONEYWELL/LeRC BL Ni 2 GLASS.

Fig. 2a — Collector Performance Correlation



(B) HONEYWELL/LeRC BLACK Ni 2 GLASS.

Fig. 2b — Collector Performance Correlation



(C) HONEYWELL/LeRC BL Ni 2 GLASS.

Fig. 2c — Collector Performance Correlation

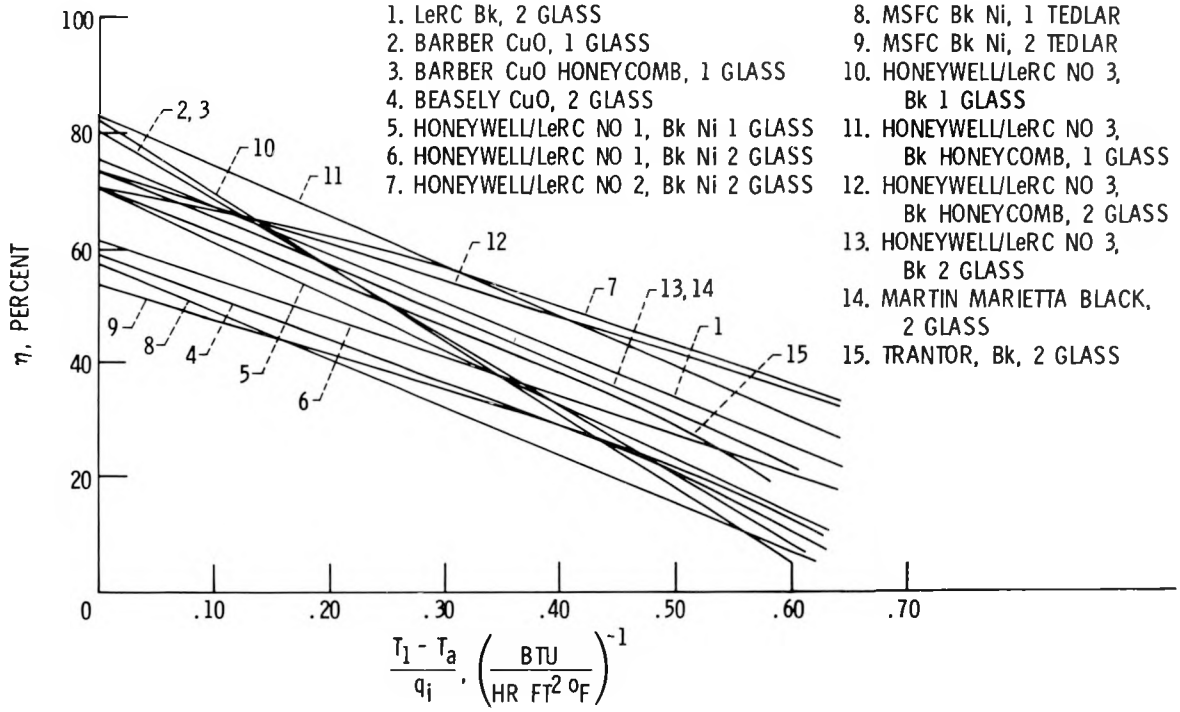


Fig. 3 — Results of Collector Performance Tests with a "Simulated Sun"

TABLE I

COLLECTOR PERFORMANCE RANKING

COLLECTOR	(a) POOL HEATING COLL.#	η *	(b) HOT WATER COLL.#	η *	(c) ABSORPTION A/C OR HEAT COLL.#	η *	(d) SOLAR RANKINE COLL.#	η *
1. LeRC Black paint, 2 glass	10	83%	11	62%	7	45%	7	34
2. Barber Cuo, 1 glass	11	83	7	60	12	43	12	32
3. Barber Cuo + Honeycombs, 1 glass	2	80	12	58	11	41	11	27
4. Beasely Cuo, 2 glass	3	80	1	55	1	35	1	22
5. Honeywell/LeRC No. 1, BL-Ni, 1 gl.	1	75	13,14	53	13,14	33	13,14	18
6. Honeywell/LeRC No. 1, BL-Ni, 2 gl.	12	73	15	52	15	31	6	17
7. Honeywell/LeRC No.2,BL-Ni, 2 glass	13,14	73	10	51	6	28	15	11
8. MSFC BL-Ni, 1 Tedlar	7	71	2	51	5	25	5	10
9. MSFC BL-Ni, 2 Tedlar	5, 15	70	3	51	9	24	9	7
10. Honeywell/LeRC No.3,Bl.Pt.1 glass	6	61	5	48	4	23	4	5
11. Honeywell/LeRC No.3,Bl.Pt. + honeycomb, 1 glass	4	59	6	45	2,3	23	8	4
12. Honeywell/LeRC No.3, Bl.Pt. + honeycomb, 2 glass	8	57	4	41	10	21	2,3	3
13. Honeywell/LeRC No.3, Bl.Pt. 2 glass	9	54	9	39	8	17	10	0
14. Martin Marietta, Bl. Pt. 2 glass			8	37				
15. Trantor, Bl. Paint, 2 glass	* q_i=250 BTU/ hr ft^2		* q_i= 250 BTU/ hr/ft^2		*q_i=250 BTU/ hr/ft^2		*q_i=250 BTU/ hr/ft^2	
	T_a = 80°F		T_a = 80°F		T_a =80°F,0°F		T_a = 80°F	

Table I — Collector Performance Ranking

TABLE II COLLECTOR PERFORMANCE PARAMETERS

COLLECTOR	F'	F_R	$\overline{U_L}$ (Btu/hr ft^2) °F	τ Per Cover	$\alpha_{Meas.}$ (1)	$\alpha_{Cal.}$ (2)	$\eta_{A/C}$
LeRC BLACK PAINT, 2 GLASS (1)	----	0.95	0.88	0.87	0.97	----	35 %
BEASLEY CuO, 2 GLASS (4)	----	0.90	0.85	0.86	0.86	----	23 %
HONEYWELL/LeRC BL-Ni 2 GLASS(7)	0.96	0.94	0.56	0.89	0.95	0.92	45 %
HONEYWELL/LeRC BLACK, 2 GLASS(3)	0.97	0.93	0.80	0.89	0.95	0.93	33 %
MARSHALL BL-Ni, 2 TEDLAR (9)	0.99	0.95	0.69	0.86	0.73	0.79	24 %

*T_1 = 200°F; T_A = 80°F; q_i = 250 Btu/hr ft^2

(1) MEASURED WITH A SPECTROPHOTOMETER

(2) CALCULATED USING EXPERIMENTAL VALUE OF $\alpha\tau$

Table II — Collector Performance Parameters

DISCUSSION

Question (Jerry R. Dunn, Auburn University): When using the collector correlation for efficiency in terms of plate temperature (Tp) experimentally, what value of Tp is used in the correlation?

Answer (Frederick F. Simon, NASA Lewis Research Center): The average plate temperature determined from plate temperature readings of from 5 to 11 positions.

Question (Douglas M. Burch, National Bureau of Standards): What is the approximate cost of a solar simulator?

Answer: Base cost without controls, data acquisition systems, and so forth, is about $15,000.

Question (Jan F. Kreider, Environmental Consulting Services): Is it possible to test concentrators on the simulator? What is the divergence angle of the beam?

Answer: The divergence angle of the beam is 9°, which places limits on the testing of the concentrating-type collectors. For collectors with low concentration ratios, the simulator should do an adequate job.

Question (Robert F. DeSantis, Kaplan & Gaunt, Architects): Have you tested any "water trickle" collectors?

Answer: Effort is presently under way to build an experimental "water trickle" collector for testing in the simulator.

Question (Benicio I. Dussan, V, Philadelphia, Pa.): The use of a solar simulator is questioned as a practical approach. Indoor conditions are just a shade of actual outdoor conditions; further, the spectral outputs and their effects on the collector are quite different. How can the costs of the simulator be warranted, since the results obtained are of little practical use?

Answer: At the Lewis Research Center we have a collector test program which involves both indoor (solar simulator) and outdoor testing. The indoor testing of collectors allows for the following advantages:

1. Convenient testing under standard conditions of sunlight, ambient temperature and wind speed. To date, this testing has permitted collector ranking based on performance for 20 collectors. This information is being incorporated into the decisionmaking process for determining the best collectors in the NASA-Langley building project. Such a standard approach allows for reproduction of results by other investigators. This was demonstrated by the work of Honeywell (Minneapolis, Minn.) who built a copy of our simulator under contract to us and shows results very close to ours. The simulator approach has also permitted Honeywell to determine optimum collector cover types and configurations. Such effects could not have been easily determined outdoors because of weather variations.

2. Controlled conditions such as obtained indoors allow for a determination of key collector parameters.

3. Performance correlations determined with the simulator have been found to be applicable to collector performance under actual conditions. A major reason for this success is the excellent spectral qualities of the solar simulator. For example, a wave-length-dependent surface such as black nickel has about a 0.5-percent error in absorptivity under the simulated sun as compared to actual sun light.

The above advantages can be had for a price tag of about $15,000.

SOLAR COLLECTOR PERFORMANCE EVALUATED OUTDOORS AT NASA-LEWIS RESEARCH CENTER

By

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INTRODUCTION

A facility was constructed at Lewis Research Center to evaluate solar collector performance for conditions that would be encountered by collectors if they were incorporated in a solar heating/cooling system. NASA-Lewis has the responsibility to select and provide solar collectors that will be incorporated in a solar heated and cooled office building at NASA's Langley Research Center in Hampton, Virginia (ref. 1). The solar project at Langley will provide a test bed for determining actual field performance of components that comprise a solar heating/cooling system. Test results obtained from the outdoor test facility at Lewis will provide one of the inputs to the selection process for the collectors to be used on the solar project at Langley.

In addition to providing initial collector performance data, the outdoor facility will enable collector durability and early degradation rates to be evaluated for operating periods of several months. Also, the data obtained from the outdoor tests will be correlated with data obtained using a solar simulator.* This will allow a determination of the extent to which collector performance can be predicted by using data obtained in the simulator facility. This paper describes the outdoor test facility and presents some preliminary performance data.

DESCRIPTION OF FACILITY

A simplified schematic of the flow loop is shown in figure 1. The liquid in the flow loop is a mixture of 50 percent ethylene-glycol and 50 percent water by weight. A conventional home hot-water heater, 80 gallon capacity, is used for storage. The electric heating elements in the storage tank are controlled by a thermostat. The storage tank heaters provide a ready means to raise the temperature of the entire liquid inventory when desired. A centrifugal pump, driven by a 1/4 horsepower electric motor, circulates the liquid. A filter provides

*The solar simulator facility at the Lewis Research Center is described in companion paper authored by Fred Simon elsewhere in this document.

continuous filtration of the liquid. A conventional air-liquid heat exchanger, with an on-off fan control, is used to reject energy when desired. A by-pass around the heat exchanger and the associated proportional control valves permit modulation of the liquid temperature at the outlet of the heat exchanger.

A flow through each collector is manually adjusted with a remotely operated valve. The flow rate through the collector by-pass line is controlled to maintain a constant pressure in the collector inlet manifold. Thus, when the flow rate through one collector is varied, the flow through the remaining collectors remains constant with no adjustment of the flow-control valves. The flow rate through each collector is determined with a calibrated turbine-type flowmeter. Auxiliary heaters with electric immersion elements are located at the inlet of each collector. These heaters provide a controlled variation of inlet temperature from collector to collector. The liquid discharge from the collectors is returned to the storage tank. An expansion tank accommodates volume changes of the liquid inventory.

When completed the outdoor collector facility will include two identical flow loops with a capability of testing ten collectors simultaneously. One of the flow loops is presently completed and is shown in figure 2. The range of possible test conditions is presented in figure 3.

The instrumentation is summarized in figure 4. In addition to the collector performance and solar insolation data, the following weather data are recorded: air temperature, wind speed and direction, and relative humidity. At the present time all temperatures are measured with chromel-constantan thermocouples, ISA type E. The temperature measurement method is being reviewed and may be modified in the future. Presently only a single pyranometer, mounted in the plane of the collectors, is used to measure solar flux. The remaining pyranometers and the pyrheliometer, for direct or beam radiation, will be installed when available. The solar flux will also be integrated continuously in the future.

PRELIMINARY RESULTS

Preliminary results are presented in figure 5 for a collector fabricated at the Lewis Research Center from two copper heat-transfer panels (Thermon Manufacturing Co.). The panels were sprayed with a nonselective black paint ($\alpha = 0.97$). Two glass covers were placed over the panels and four inches of fiberglass insulation beneath. The panels, plumbed in parallel, each measured 22 inches by 45 inches. The outside dimensions of the collector frame are 48 inches by 49 inches. In figure 5, the instantaneous collector efficiency,

$$\frac{\dot{m}\, C_p\, (T_{out}-T_{in})}{q_{solar}\, A_{absorber}}$$

is plotted as a function of the ratio

$$\frac{T_{in} - T_{amb\ air}}{q_{solar}}$$

This format is particularly useful when employing the collector design factors presented in references 2 and 3. A general equation developed therein expresses the collector efficiency as

$$\eta = F_R \left[\alpha\tau - \frac{U_L (T_{in} - T_{amb\ air})}{q_{solar}} \right].$$

By plotting the data as shown in figure 5, the values F_R and U_L are readily obtained. Knowing the effective $\alpha\tau$ product, F_R can be determined knowing the vertical intercept. Then, knowing F_R and the slope of the curve, U_L can be determined. These early data are presented primarily to demonstrate the approach to be taken for presenting data. No correction was incorporated for the effects of wind, incident angle, sky temperature, etc. In the future, using the integrated values of solar flux, the collector efficiency will be determined on both an hourly and daily basis. The collector performance determined outdoors will be correlated with data obtained using a solar simulator (ref. 4 and 5) to confirm the simulator approach to acquiring performance data.

CONCLUDING REMARKS

A facility to determine solar collector performance outdoors has been constructed. Preliminary performance data have been obtained. Performance data obtained from the outdoor tests will be employed as one of the bases for selecting collectors for installation on the solar project at NASA-Langley. The solar simulator approach to obtaining collector performance will hopefully by confirmed by correlation of data acquired outdoors with data previously measured in a solar simulator facility.

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2. H. C. Hottel and A. Whillier: Evaluation of Flat-Plate Solar Collector Performance. Trans. Conf. on the Use of Solar Energy--The Scientific Basis. Tucson, Arizona, October 31-November 1, 1955, Vol. II, Part 1, Section A, pp. 74-104.

3. R. W. Bliss, Jr.: The Derivation of Several "Plate-Efficiency Factors" Useful in the Design of Flat-Plate Solar Heat Collectors. Solar Energy, Vol. 3, No. 4, pp. 55-64.

4. F. F. Simon and P. Harlamert: Flat-Plate Collector Performance Evaluation, The Case for a Solar Simulator Approach. NASA TM X-71427, 1973.

5. R. W. Vernon and F. F. Simon: Flat-Plate Collector Performance Determined Experimentally with a Solar Simulator. NASA TM X-71602, 1974.

SYMBOLS

$A_{absorber}$	Area of absorber, ft^2
C_p	Specific heat of fluid, Btu/lb°F
F_R	Overall collector plate heat removal efficiency, dimensionless
q_{solar}	Total flux in plane of collector, Btu/hr ft^2
$\dot{m}$	Fluid mass flow rate, lb/hr
$T_{amb\ air}$	Ambient air temperature, °F
T_{in}	Fluid temperature at collector inlet, °F
T_{out}	Fluid temperature at collector outlet, °F
U_L	Overall heat loss coefficient, Btu/hr ft^2°F
α	Absorptivity of collector absorber, dimensionless
η	Collector efficiency, dimensionless
τ	Transmittance of collector cover system, dimensionless

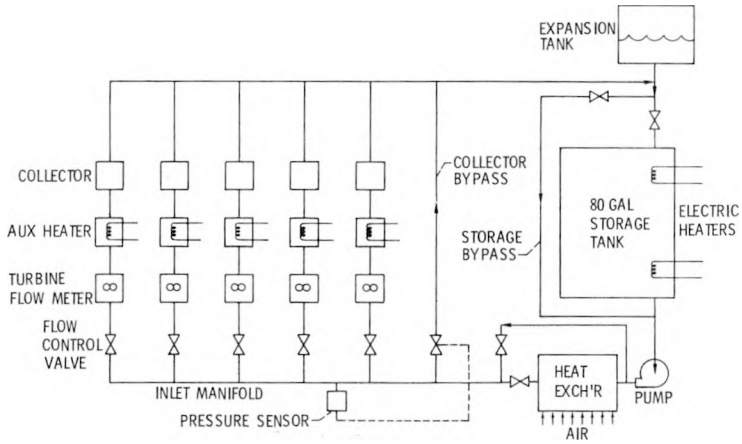


Fig. 1 – Schematic of Outdoor Collector Facility

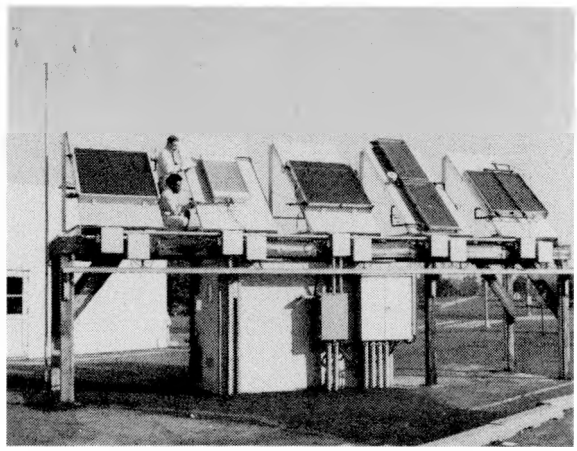


Fig. 2 – Outdoor Collector Facility

- FLOW ---------- TO 3 GAL/MIN
- INLET FLUID TEMPERATURE ---------- AMBIENT TO 200°F
- TILT ANGLE ---------- 20 TO 60 DEGREES
- COLLECTOR SIZE ---------- UP TO 4 X 8 FT

Fig. 3 – Range of Outdoor Test Conditions

- COLLECTOR

  FLOW RATE

  TEMPERATURE

  - IN
  - OUT
  - PLATE
  - GLASS

  PRESSURE

  - IN
  - DELTA P

- SOLAR FLUX

  TOTAL IN PLANE OF COLLECTOR (PRESENT)

  TOTAL HORIZONTAL
  DIFFUSE HORIZONTAL
  DIRECT
  } (FUTURE)

Fig. 4 – Instrumentation for Outdoor Collector Tests

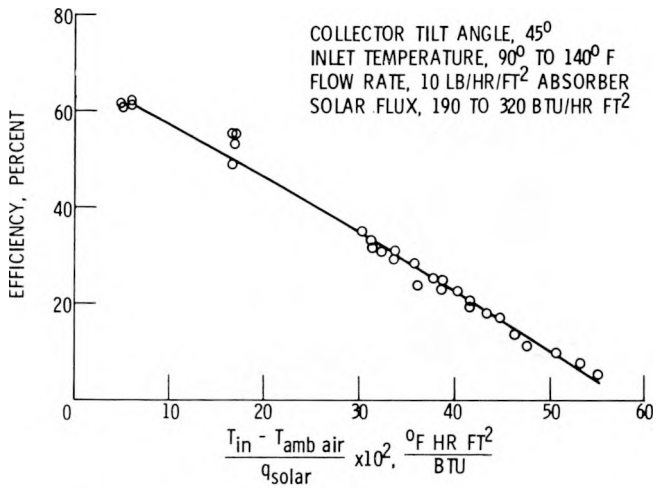


Fig. 5 – Performance of Lewis Collector, Preliminary Data

DISCUSSION

Question (Richard R. Lewchuck, PPG Industries, New Products Division): There are standard accelerated tests for evaluating the effects of humidity and temperature on glazing and double-glazed or insulated glass products. Do you plan to use these tests or standards for evaluating durability of collectors for the Langley project?

Answer (Richard W. Vernon, NASA-Lewis): We are not at present conducting any accelerated tests, but we may in the future.

Question (James E. Hill, National Bureau of Standards): In comparing the indoor and outdoor test results, were the indoor test results corrected for the outdoor test condition?

Answer: For the preliminary results, we corrected for the incidence angle only.

52,121

SURVEY OF COATINGS FOR SOLAR COLLECTORS

By

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Four high-performance, moderate-cost, widely available coatings have been investigated. Two of these--black copper and black nickel--were previously known to be solar selective. The solar selective properties of the other two--black chrome and black zinc--were discovered at the NASA Lewis Research Center, Cleveland, Ohio. The general broad solar selective characteristics of all four coatings are very similar.

The most intensive investigation of solar selective coatings conducted at NASA-Lewis has been made on black chrome in order to determine the preparation method which would produce its optimum solar selective properties of maximum absorption across the visible spectrum and minimum emittance in the infrared.

When black chrome is used as a solar selective coating on steel, the steel is first plated with nickel, both to produce low emittance and also to prevent the steel from rusting, since the black chrome provides no such protection. If black chrome is plated on aluminum, the aluminum is first plated with either nickel, after zincating, or plated directly with chromium, prior to plating with black chrome. The optimum solar selective properties of black chrome are obtained by plating the black chrome over dull nickel for one minute at 180 amps/ft^2 using Harshaw Chromonyx (ref. 1).

The second new solar selective coating discovered is black zinc. This solar selective coating is produced from a high zinc electroplate by susbsequent conversion with a chromate dip. The zinc is conveniently electroplated from Harshaw NEOSTAR-AFA at 40 amps/ft^2.

Measurements have also been made of the reflectance of the previously known solar selective coatings of black copper and electroplated black nickel. The reflectance measurements form the basis for calculation of visible absorptance and infrared emittance. The measured reflectance of the black chrome, black zinc, black copper, and black nickel are shown in figure 1, together with the nonselective coatings of black paint and black ceramic enamel.

Comparative cost of coating solar collectors with these various selective and nonselective coatings was determined by obtaining, from processors established in the coating industry, quotations for

coating a lot of 500 panels. Quotations were in agreement within approximately 15 percent between processors and do include handling, surface prepreparation and coating materials cost. The results are shown in Table 1 together with the characteristic values of absorptance, as integrated over the solar spectrum, and of the infrared emittance. Some of the coatings, such as the alkyd enamel, have a material cost which is a large fraction of the total applied cost, while others, such as ceramic enamel, have a processing cost which is a large fraction of the total applied cost.

As an additional component of the evaluation of the various coatings for solar collectors, a limited amount of data has been assembled on the durability of coatings. This information on durability has been summarized in Table 2.

Summary

Ceramic enamel is more solar selective, (i.e., has high solar absorptance in combination with low infrared emittance)than organic enamel, but neither is as solar selective as black chrome, black copper, black zinc or black nickel. Ceramic enamel is matched only by black chrome in durability and wide availability. Ceramic enamel and organic enamel have approximately the same cost, and both are currently slightly lower in cost than black chrome, black copper or black zinc. Black nickel is relatively unavailable and, because of that, realistic cost comparisons are not possible.

Reference

1. McDonald, G. E.: Refinement in Black Chrome for Use as a Solar Selective Coating. NASA TM X-3136.

TABLE 1

Cost of Coatings for Solar Collectors

Coating	Cost $/ft^2$	Absorptance α	Emittance ε
ALKYD Enamel	.50	0.9	0.9
Ceramic Enamel	.50-.60	0.9	0.5
Black Chrome	.70-.80	0.9	0.1
Black Copper	.50 (base metal not included)	0.9	0.1
Black Zinc	.70-.80	0.9	0.1
Black Nickel	No quotations	0.9	0.1

TABLE 2

Durability of Coatings for Solar Collectors

Coating	Durability
ALKYD Enamel	Limited at high temperature
Ceramic Enamel	Eminently stable
Black Chrome	Stable
Black Copper	Patinates with moisture
Black Zinc	Not completely defined
Black Nickel	Destroyed by moisture

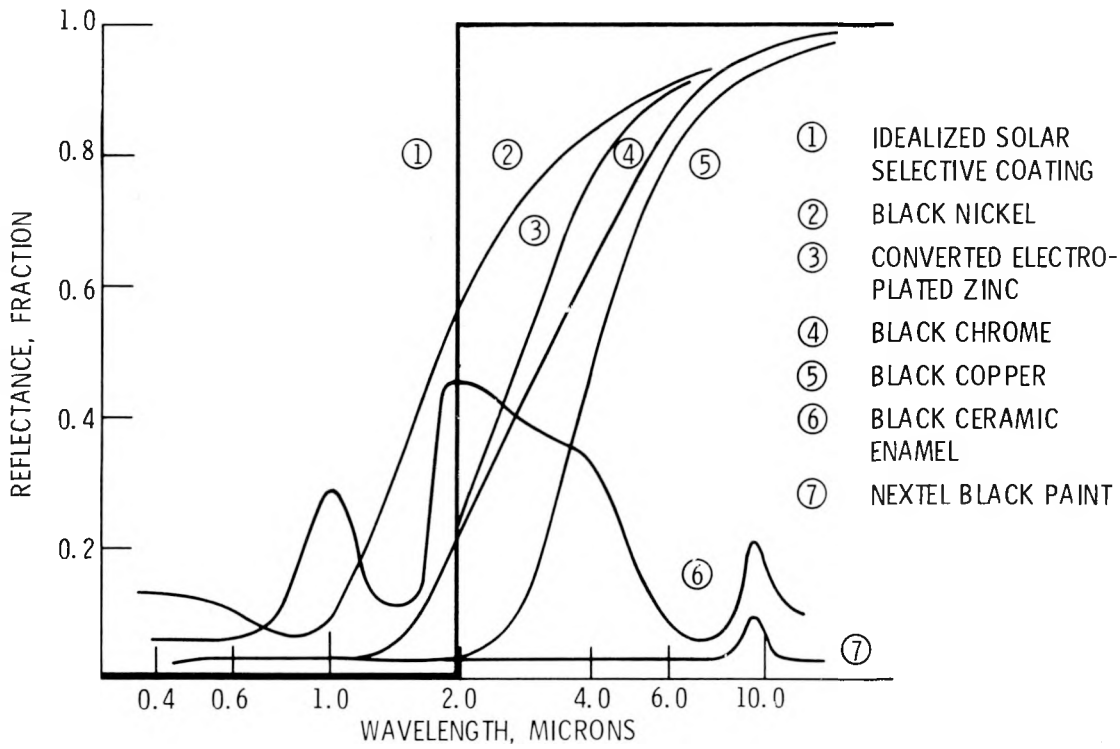


Fig. 1 — Reflectance of Coatings for Solar Collectors

DISCUSSION

Question (Redfield W. Allen, University of Maryland): Do you have any information on the off-normal reflectance of selective surfaces?

Answer (Glen E. McDonald, NASA Lewis Research Center): Not as a function of angle. We are measuring some. Some of these solar selective surfaces are very specular—mirrorlike. With these, of course, you get a lot of reflectance as soon as you get to an off-normal angle. On the other hand, if you produce a dull finish under your solar selective coating you can increase the absorptance by another 5 percent just by decreasing reflectance on the material. This can be done two ways: by mechanically roughening the surface by plating over, for example, a 30-microinch finish instead of a ½-microinch finish; or, by plating over a material such as dull nickel. You plate over dull nickel instead of bright nickel, and you increase absorptance and do not seem to change the infrared emissivity. You maintain high infrared reflectance, low infrared emissivity, but you also get a few percent—approximately 5 percent—decreased reflectance or increased absorptance in the visible.

Question (Richard LaRosa, Hazeltine Corporation): When you referred to "ceramic" did you refer to the pigment or to the binder?

Answer: Commercial ceramic enamel, as far as I know, is a combination of both binder and pigment.

Question (John C. Goldsmith, National Academy of Sciences): Have you evaluated other types of organic enamels?

Answer: No.

Question (Walter B. Bienert, Dynatherm Corporation): Do you have any experience with a copper-blackening process called "ebonize"?

Answer: Yes. We have done some work with black nickel, probably a mixture of finely divided metallic nickel, nickel oxide, and some nickel sulfides. We have done a little work with black chrome, probably a mixture of superfinely divided chrome metal with some subchrome oxides. And we did some work on oxidizing copper to produce copper oxide. In all of these materials, the solar selective property is very dependent on film thickness. It is easy to produce such a film on a copper base by oxidizing over to this copper oxide in a number of ways, but it is is much easier to exceed the critical film thickness and destroy the emissivity while still maintaining high absorptance.

Question (Richard R. Lewchuck, PPG Industries): Martin-Marietta's coating has been reported to have a 99.5-percent absorptance across the total spectrum. Would you comment on the differences in the measurements shown in your slides?

Answer: The slides were not intended to be that accurate; they are within several percent, but do not show such fine values.

Question (Harold S. Lewis, Consulting Engineer): Do you have any absorptance and emittance values for anodized aluminum?

Answer: If you regard the Martin-Marietta Martin black as anodized aluminum, yes. The absorptance is 99 percent or better, as mentioned by Mr. Lewchuck; the emissivity is approximately the same. In other anodized aluminum, with a very thin aluminum oxide film, you have a reflectance in the visible of 10 to 20 percent but a low emissivity—eight-tenths to nine-tenths of reflectance. You have low emissivity but not very good absorptance. As you increase the film thickness you increase the absorptance. When you go to a black film the emissivity climbs to three-tenths, four-tenths, and higher.

SESSION 9

PANEL DISCUSSION BY COLLECTOR USERS

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USERS' EXPERIENCE WITH SOLAR WATER HEATER COLLECTORS IN SOUTH FLORIDA

Jerome E. Scott
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University of Delaware
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During the late 1930's solar energy was the dominant method for providing hot water service to single-family residences, apartment buildings, and other small commerical buildings. Perhaps as many as 60,000 water heaters were installed in South Florida and many are still in use today. Unfavorable economic shifts, system failures, and the emergence of large-scale developers resulted in the near extinction of the industry. Only a very few new installations are being made today. Although our study did not focus on collectors specifically, some useful observations on collectors were obtained.

Nearly all of the systems installed relied on the thermosiphon principle with galvanized steel storage tanks positioned above the collectors. The typical collector used is shown in Figure I. The copper tubing was attached in serpentine fasion to the copper sheet by soldering (the entire length in good designs). The coils and copper sheet were then painted with a flat black paint and encased in a galvanized steel case (absorber box). When properly sized to a family's water requirements these systems provided ample hot water at 140^{o}F except for a very few days of the year when periods of prolonged cloudiness occurred. The majority of the systems did not include boosters for alternative heating. These were added to existing units and installed as part of the original equipment after World War II as consumption of hot water increased.

The evidence obtained from homeowners and representatives of the solar heaterfirmsindicates that the collectors, considered alone, were very durable and nearby trouble-free. Many have been in operation for over 30 years without a single problem. Even the extraordinary freeze of 1950 in the Miami area failed to damage collectors made with soft copper (collectors fabricated with hard copper tubing did not fare so well). Other than a few leaks at the tubing connections and occasional glass breakage due to hurricanes and other storms, the collectors seem to perform well and last almost indefinately except where roofs required replacing. Re-roofing often required replacement of the absorber box due to corrosion which caused the assembly to fall apart.

Indirect evidence on user's attitudes toward collectors was obtained by asking why those families who discontinued using their solar units chose to do so. Table I tabulates a content analysis of the respones obtained from this subsample. Other than one homeowner who cited storm damage, little in the data suggests serious collector problems. The principal reasons for discontinuance were damage due to tank leaks, insufficient hot water, and the expense of replacing a tank after failure. It is also noteworthy that none of this subsample remarked on the aesthetic quality of the units. Indeed,

when a collector was built into the roof and the tank was well-concealed as a false chimney, the resulting appearance was hardly objectionable. It should be remembered, however, that the collector area is small (typically 12 x 4 feet) and it could be placed flat on the roof without much loss in efficiency due to the latitude of South Florida.

Viewed as a system, however, the collectors were related to the typical failure mode of the systems. The combination of copper tubing in the collector and steel storage tanks led to tank leaks which often caused considerable damage due to the location of the tanks. A large fraction of the tanks developed leaks after 10-12 years of service. The location of the tank also greatly increased the cost to replace a tank. Tank replacement for a detached residence is currently priced at about $500 or approximately $150 more than the cost to install an electric unit.

In summary, the collectors used in the water heating systems were durable, reliable, and performed-well under conditions of proper system design. On the other hand, the relationship between the collector and overall system performance, reliability, and costs must take into account the compatability of these types of collectors with other system components.

Table I. Reasons for Discontinuing the Use of Solar Hot Water Heaters.

	Absolute Frequency	Percent
Damage Caused by Tank Leaks	16	24.0
Insufficient Hot Water	15	23.0
Too Expensive to Repair Tanks	10	15.0
Replaced Before Failure, Unit Considered Too Old	6	9.1
Poor Position, Shading	4	6.1
Not Safe, Worrisome	3	4.5
Booster Problems	3	4.5
Too Much Rust or Sediment	2	3.0
Needed Maintenance, Bother	2	3.0
Damaged by Storms	1	1.5
Already Had Conventional Unit	1	1.5
Other	3	4.5

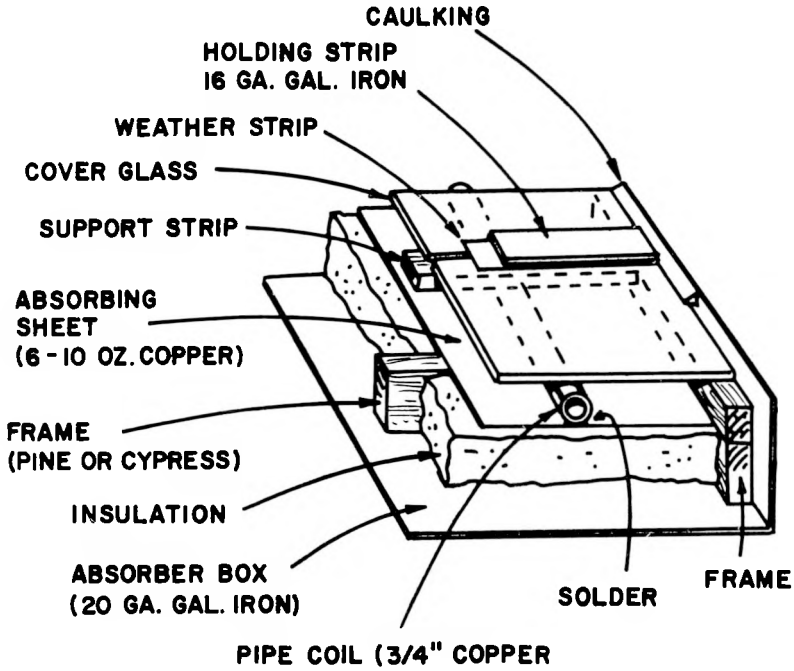


Fig. 1 — Section of Collector Assembly Showing Typical Components

DISCUSSION

Question (Horace W. McCracken, Sunwater Co.): In the Florida survey, did you turn up any evidence of scale deposition inside the collector tubes?

Answer (Jerome E. Scott, University of Delaware): We did not find evidence of scale buildup inside the collector tubes, but I should point out that our evidence is indirect. Representatives of the Miami solar firms indicated that very little scale forms inside the copper collector tubes, but that a great deal accumulates at the connection of the copper lead lines and the storage tank. Some sediment tends to collect in the tubes, but this can be flushed and does not seem to pose any significant problems, even for thermosiphon systems.

Question (Paul McCormick, Lockheed Missiles & Space Co.): You commented that only a few (2-5 percent) of the people questioned quit using the solar heater because of collector problems; yet, you showed that 15 percent quit because there was not enough hot water. Is it not likely that a large portion of this lack of hot water was actually collector problems that could not be diagnosed by the user?

Question (Roger N. Schmidt, Honeywell, Inc.): Did the solar hot water systems have auxiliary heat, and, if so, could that be why there was little or no collector dissatisfaction in your study?

Answer (in response to both preceding questions): Other than the corrosion referred to previously, which is a system problem and may impede water circulation, I don't believe the complaint of insufficient hot water is due to the collectors. There are other, more compelling, reasons for this response. The increasing use of hot water and the absence of boosters on many systems resulted in systems that became progressively underdesigned. Our estimates indicate that 41 percent of the discontinued users owned systems that did not include a booster. In fact, we estimate that nearly 32 percent of the solar water heaters still in use do not have boosters.

Comment (Bruce G. Nimmo, Florida Technological University): It may be of interest to know that the State of Florida is funding Florida Technological University for a technical assessment survey of the types of unit that Dr. Scott has reported on. The idea is to complement the attitudinal survey work done by Dr. Scott and others in Florida.

Comment (Erich A. Farber, University of Florida): Our surveys of 15,000 households over the years indicated that the solar water heaters were designed in the 1930's without regard to washing machines and dishwashers. The change in lifestyle produced loads that the system was not designed for and thus could not provide.

Response (Mr. Scott): It would be useful to compare our findings.

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AN ARCHITECT'S VIEW

William H. Grover, AIA
Charles W. Moore, Associates
Essex, Connecticut 06426

Charles W. Moore Associates is a firm of architects in Essex, Connecticut, whose experience over the past 10 years has been largely in residential design, from a college campus at Santa Cruz in California to multi-family housing, elderly housing, and urban renewal projects throughout the United States. We have also been the architects for numerous single family houses ranging in price from $6,000 to over $400,000 and for a variety of commercial buildings as well.

Our interest in solar heating of buildings stems from our association with Professor Everett Barber of Yale, whose "Sunworks, Inc." is now producing flat plate liquid collectors for the U.S. market. We started working with Professor Barber in 1972 and his experimental residence, which we designed, is now under construction in Guilford, Connecticut.

We have studied various collectors and heat storage systems and are currently using flat plate liquid collectors with copper absorbers, and water as a heat storage medium. Our studies have shown that for most single family residences in the northern U.S., we can do without air conditioning altogether if careful consideration has been given to orientation, sunshading, and natural ventilation. For this reason, we have concentrated on the real economic necessity, which is space heating and domestic hot water heating.

We have recently limited ourselves, in the design of all residences, to design heat loss of 35 BTUH/sq.ft. of heated floor space, and hope to reduce this number to 20 BTUH/sq.ft. or less through various strategies of insulation and glazing. We have noted reluctance on the part of owners to use solar heat because they think it is complicated and expensive, and they are concerned with maintenance and product warantees. We have noted surprisingly little objection to the appearance of solar collectors if they are integrated into the design of the residence in an unobtrusive way.

In response to the suggested topics, provided to the panelists, we believe that collectors should be guaranteed against defects in materials or workmanship by the manufacturer in the same way that a boiler or bathtub is guaranteed by its manufacturer. We would like to see a usable lifetime of at least 20 years and, of course, as much more than that as possible.

We see no code or weight problem in new structures but could imagine some problems in retrofitting if collector weights exceeded three lbs./sq. ft. Wind loads will be no problem in new construction but will certainly require careful study in retrofitting.

We prefer flush mounted collectors from an aesthetic standpoint, but are concerned about leakage and the possible resulting damage to interior finishes. At present there is a coordination problem with flush mounts:

will the collectors arrive at the job in time to be installed or will closing up the structure be delayed? If they arrive too early, there may be a breakage problem. We have gone to a method where the collectors are placed on top of the roof.

We prefer to specify flat plate collector performance on the basis of thermal efficiency: A ratio of the heat absorbed by the transfer fluid to the incident solar radiation when the collector is normal to the sun's rays. We use this factor in our own formulas for determining required collector area and storage volume for residential buildings.

We have a simple rule of thumb for roughly determining whether a solar heating system is economically justified for the owner: We calculate the estimated yearly heating cost of the building and multiply by 10. That's the amount of money the owner could invest at 10% and get a yearly return equal to his fuel costs. That amount, in addition to the cost of a normal heating system is, we believe, reasonable expenditure for a 100% solar heating system. That's just a rule of thumb, of course, which can change as fuel costs go up or as interest rates go down. (It also assumes the owner has that much capital to invest.)

We hope to see good, trouble free, long lasting collectors selling for $5 to $6 per square foot installed.

Finally, I am encouraged by recent progress and interest in solar heating of buildings, particularly in public acceptance of the concept. I'm hopeful that manufacturers of collectors will interpret this interest as a market sufficient to warrant mass production and the consequent reduction in cost. It's essential for all of us to demonstrate to the American public that solar heated buildings are no longer the product of research laboratories, but are possible and practical today, that they are in fact one of the best short term solutions to our energy dilemma.

Figures 1 through 8 show the Barber residence in Guilford, Conn., now under construction. It's intended to be as nearly energy-independent as possible under the economic constraints of the owner. Heating is provided by a liquid collector/storage system and electricity will be provided in part by a wind electric generator. A significant breakthrough, we think, is that the house is being financed through the Connecticut Savings Bank, the first such financing of a solar heated house we know of. The house contains numerous energy conserving devices and inventions which we hope will set an example for architects and for the housing industry in the U.S.

Finally, if we are designing buildings whose life span is to exceed perhaps fifty years, these buildings will outlast the world's supply of petroleum. The relatively small initial cost of solar heating these buildings must be compared with the substantial cost of adding such systems later or providing heat from other more expensive sources.



Fig. 1 – Barber House: View from Southeast

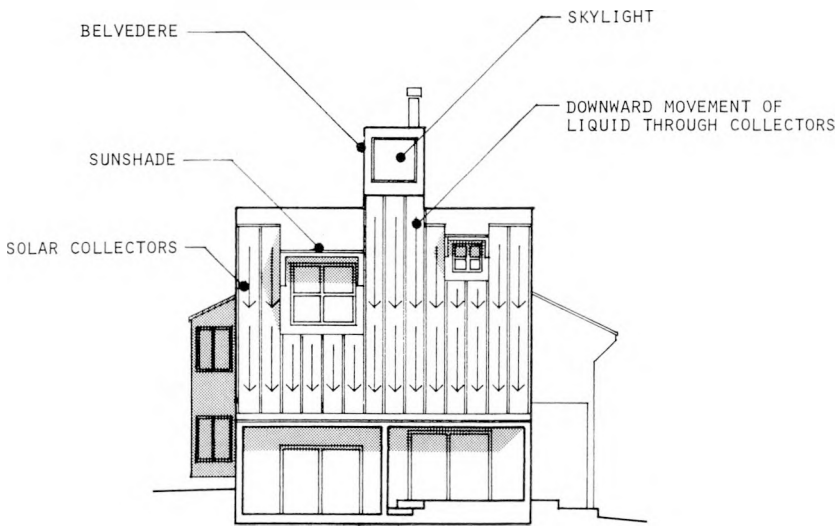


Fig. 2 – Barber House: South Elevation

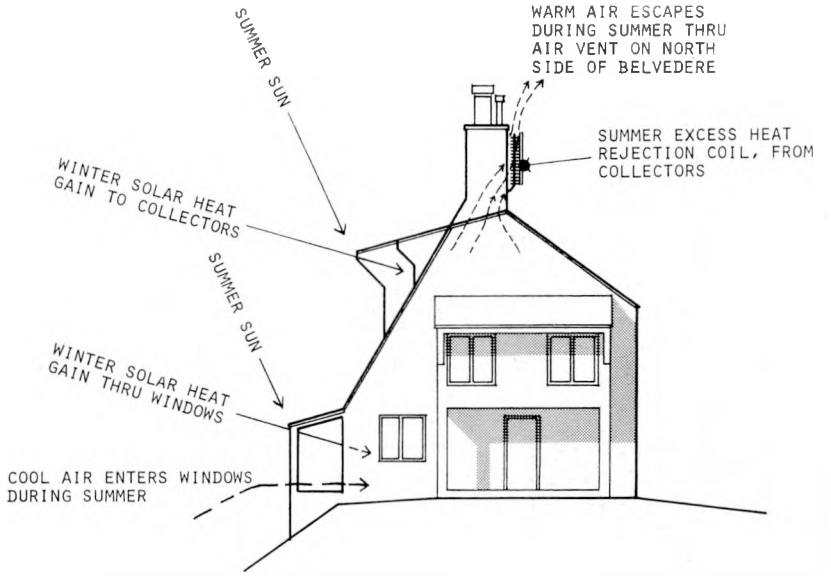


Fig. 3 – Barber House: East Elevation

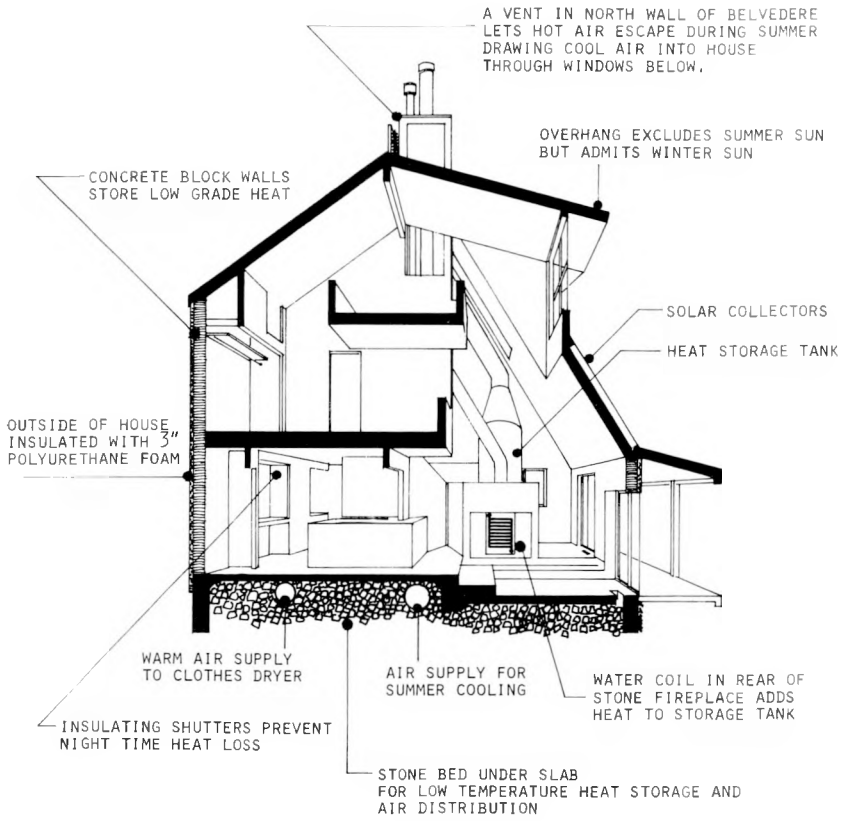


Fig. 4 – Barber House: Section Looking East

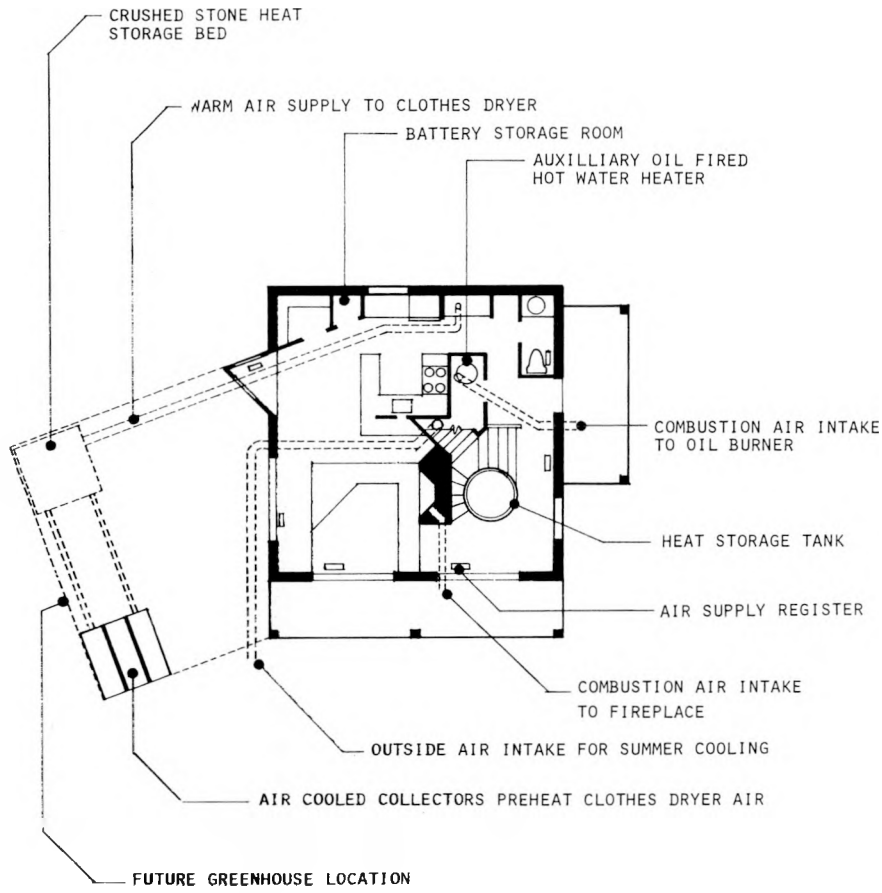


Fig. 5 — Barber House: First-Floor Plan

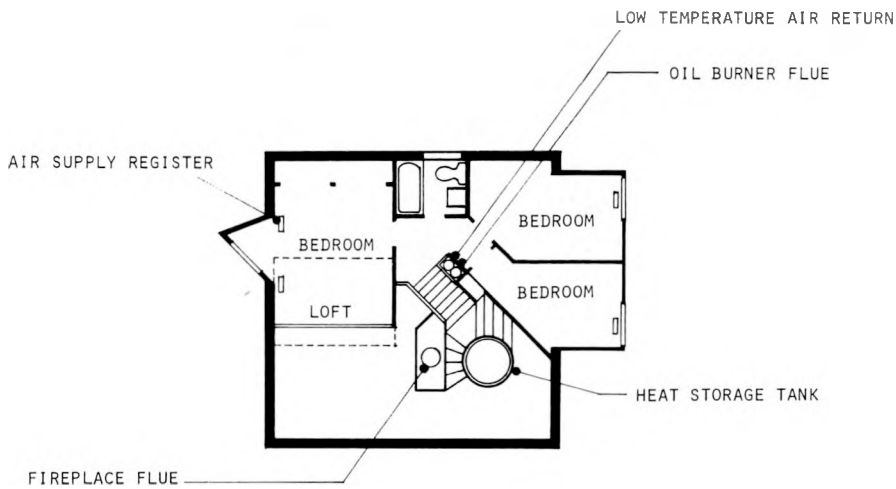
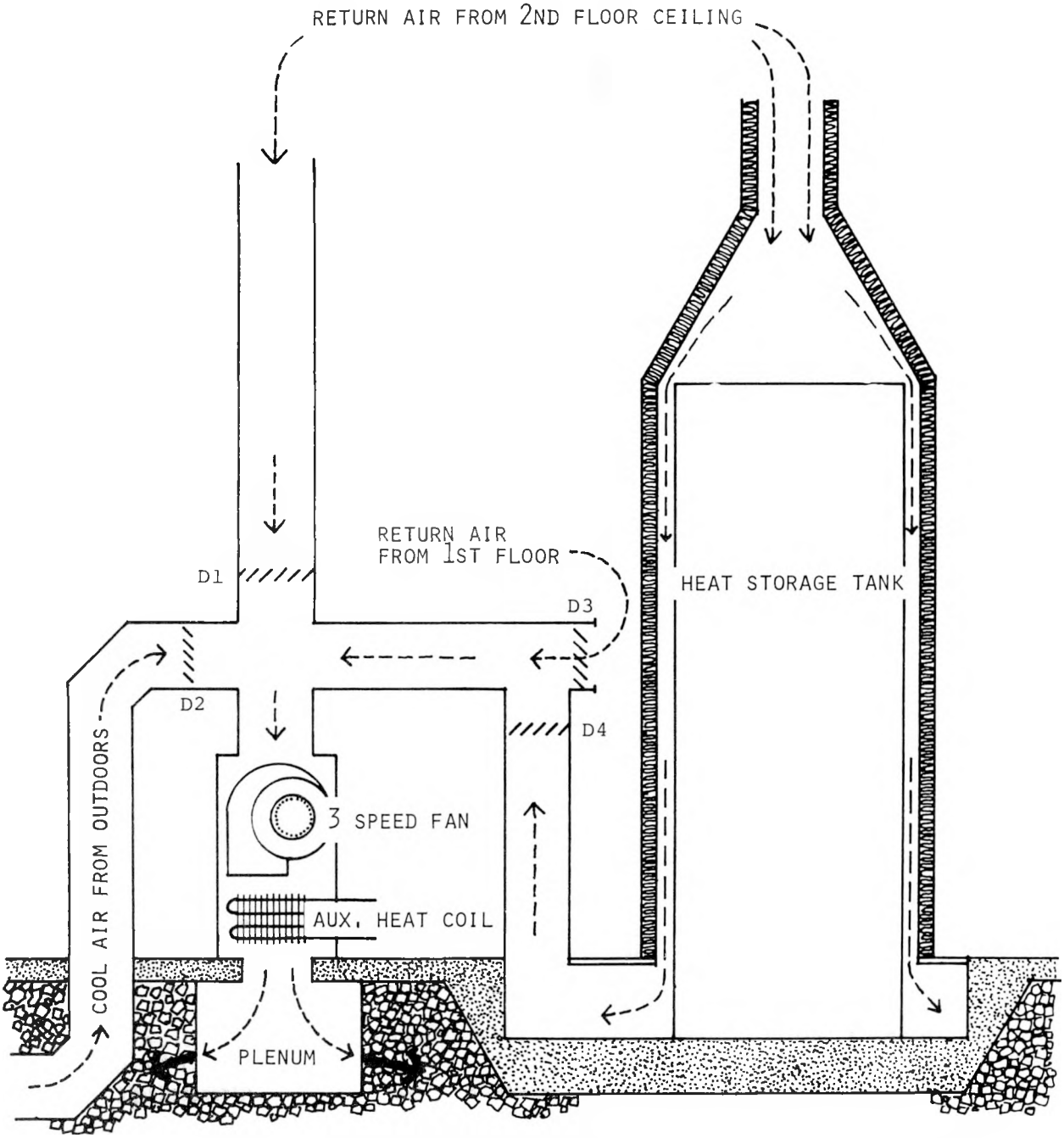


Fig. 6 — Barber House: Second-Floor Plan



WINTER - NIGHT-TIME HEATING D1,D2,D3 CLOSED, D4 OPEN, FAN ON.
- DAY-TIME STORAGE OF OCCUPANT AND SOLAR GAIN THRU WINDOWS, INTO STONE UNDER FLOOR. D2,D3,D4 CLOSED, D1 OPEN, FAN ON.

SUMMER - NIGHT-TIME COOLING FROM OUTSIDE AIR INTO STONE, WINDOWS OPEN, D1,D3,D4 CLOSED, D2 OPEN, FAN ON.
- DAY-TIME COOLING OF HOUSE FROM COOLNESS STORED IN STONE, D2,D1,D4 CLOSED, D3 OPEN, FAN ON.

Fig. 7 – Barber House: Heating System Diagram

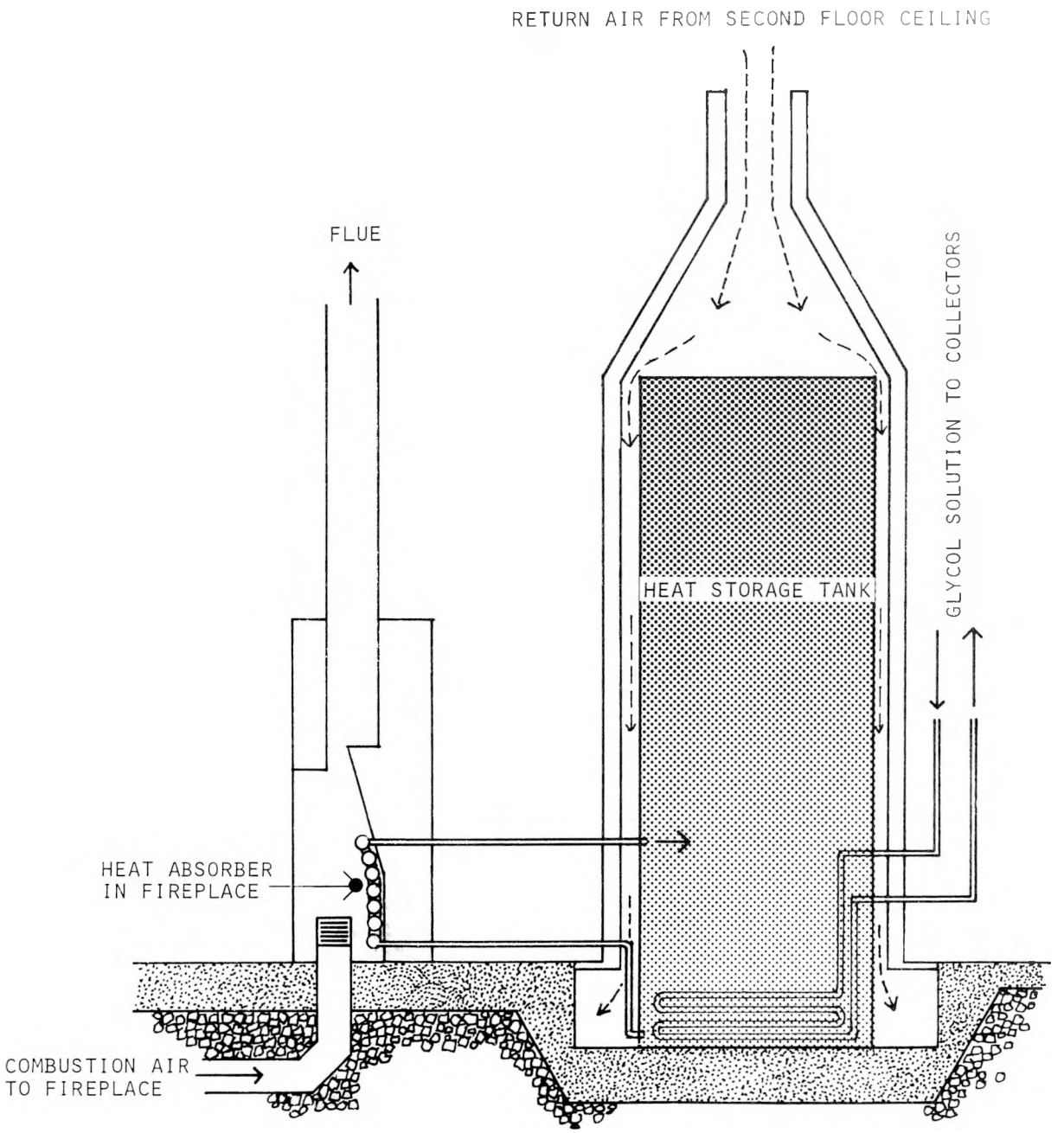


Fig. 8 — Barber House: Section Through Heat Storage Tank

DISCUSSION

Question (James Poorbaugh, General Solar Joint Venture): Is urethane foam safe for residential and collector insulation?

Answer (William H. Grover, Charles W. Moore Associates): We have been advised that the form we are using has a relatively low flame-spread rating, and that the major problem associated with urethane foam (toxic smoke when burned) is not likely to be dangerous when the foam is used on the exterior surface of the building. The foam on the Barber house will be coated with a cement-based fireproofing paint.

Question (F. John Allen, Garrison, N.Y.): How are you going to deal with the expansion or contraction of foam on the outside of the building?

Answer: We have experienced no cracking or expansion-contraction problems when the foam is applied on the outside of a building's walls or roof. The new urea-based foams are much cheaper and safer, but somewhat less efficient, and can only be used as filler insulation.

Question (Alfred L. Alk, Energy Resource Corp.): Has the local building inspector approved the solar heating system, or required a conventional system as well?

Answer: The only problem we have encountered in this regard is possible leakage of glycol coolant into drinking water, but this has been solved by various check valves and by isolation of the glycol loop from potable water supply. There is no law requiring a conventional backup heating system (so far as I know) although the Barber house does have a 55-gal oil-fired hot water heater for auxiliary heat.

Question (Matthew J. Barrett, Dames & Moore): You gave a formula for determining acceptable investment cost for a solar heating system: C = normal heating system investment + 10 times the annual fuel cost. Doesn't this neglect the need for a conventional heating unit along with the solar heat unit?

Answer: We use (as a rule of thumb only) 10 times the estimated annual heating fuel cost if a conventional system were used instead of the solar. If an auxiliary system is used (as it almost always is) we use 10 times the estimated cost of fuel saved by the solar system. So if the estimated yearly fuel cost is, say, $800 and the solar system is to provide 60 percent of the heat requirement, the solar system would save about $480 per year. The rule of thumb says you shouldn't spend more than $4,800 in addition to the cost of a normal system. This method is based on the assumption that you could take the $4,800 and invest it at 10 percent, getting a $480 return each year which you could spend on fuel oil. (We suggest it is better to invest in the solar system.) This is admittedly pretty unsophisticated but it's close, and a very quick way to answer the first question which comes up: How much does it cost?

Question (Charles P. Turner, National Oceanic and Atmospheric Administration): What is the window area of the Barber house? How big is the problem of large window area and what techniques are possible to use large window areas without excessive penalties in cost: thermal pane, awnings, shutters?

Answer: The largest glass areas of the Barber house are facing south and are shaded in summer by the porch roof and dormer overhangs. All windows have thermal curtains or shutters inside the house to substantially reduce heat loss at night. The north side of the house has only 32 ft^2 (insulating) glass compared to 145 ft^2 on the south side, 98 ft^2 on the west, and 48 ft^2 on the east.

Question (William B. Zimmerman, Island Earth Designs): Have you considered the use of collectors integrated into the structure, and using Filon-type greenhouse panels for both collector cover and roof surface?

Answer: Yes, we have considered practically every kind of material, and at present we have chosen to install the collectors on top of an asphalt shingle roof and to use glass for the collector cover. These decisions were based on cost efficiency and the possibility of damage to the house from fluid leakage.

Question (Alan S. Hirshberg, Jet Propulsion Laboratory): How do you achieve an effect of flush mount even when you place the collector on top of the roof rather than cut into it?

Answer: By using a wide-rake trim piece and a combination ridge-vent trim piece that overlaps the top of the collectors.

Question (Lyle R. Bruss, University of Wisconsin): How much collector area and heat storage space is used in comparison with the floor space of the home?

Answer: Floor area of the Barber house is 1,300 ft^2, collector area is approximately 400 ft^2, and storage is 2,000 gal (water).

THE CONSULTING MECHANICAL ENGINEERS' POINT OF VIEW

PETER FLACK
FLACK + KURTZ
NEW YORK, NEW YORK

Solar energy is an area that has been dominated by Government funded projects on one side and people working in their back yards on the other. The heavily funded projects can pay to have special equipment built without concern for cost. The back yard people build things themselves without counting the cost of their own time. We are in a middle position.

As a consulting engineering firm we must produce a working system:

1. At reasonable cost.
2. With available components.
3. That can be constructed by a general contractor.
4. That can be run by people without special training.
5. That "I" can put "my" stamp on as a professional engineer stating that this system will work.

In order to accomplish this we have had to develop some of our own methods of analysis in addition to staying abreast of reasearch and new developments, while thinking in terms of existing components to accomplish innovative designs.

In some instances we have been forced to innovate; because of the corrosion problems with aluminum Rollbond collectors and the high cost of copper collectors. We have utilized heat transfer oil as collector fluid for the Madeira School. These oils (Shell Thermia 33, Exon Calloria 43 and others) have been used in heat transfer applications for years in process industries but their application for solar collection is new.

Coordination between engineers and architect and clients is extremely important in order to produce an economical practical solar collector system. Arthur Cotton Moore, Architects worked with Flack + Kurtz very closely in the design of the Madeira School Science Building producing an energy conserving building with the solar collector integrated in the roof design. This proved to be the most cost effective design for this situation.



Fig. 1 — View of the West Facade (at Left) and the South Facade of the Proposed ENCON Office Building, Showing the Solar Collectors and the Deep Louvers

DISCUSSION

Question (Richard P. Lecuyer, Pratt & Whitney Aircraft): In your study of the Manhattan office building, what percent of the heating and cooling requirements can be supplied by solar power?

Answer (Peter Flack, Flack & Kurtz, Consulting Engineers): On a seasonal basis, estimates are cooling 20 percent, heating 30 percent.

Question (David Waksman, National Bureau of Standards): What is the toxicity and flammability of the heat-transfer oils that you mentioned in your talk, and would present building codes permit their use?

Question (Richard L. Field, USN Civil Engineering Laboratory): How toxic is heat-transfer oil?

Answer (in response to both preceding questions): The oils are nontoxic; flash points are 375° F or higher. Heat-transfer oils have been widely used in snow-melting systems. The collectors are out of doors, piping can be run in protected areas, and no code problems are anticipated.

Question (Howard S. Katz, Sunearth, Inc.): When using the oil with a heat exchanger, what is the ΔT across the exchanger for this system and the costs per unit of the oil?

Answer: The ΔT across the heat exchanger is 30° F. The oil cost is $1.50-$2 per gal.

Question (Alan S. Hirshberg, Jet Propulsion Laboratory): In reference to the New York City office building, are you worried about a subsequent building being built and shading your collectors? How will you guard against this?

Answer: The Encon Building was located on a specific site, and the existing development, all recent, was considered. For other structures three-dimensional zoning, as with air rights or transfer-development rights, will have to be considered.

Question (Mr. Hirshberg): Given the historic pattern of communication between architects and mechanical engineers, do you really think that communication will be improved, and how do you think this can be brought about?

Answer: Keep trying!

Question (Herman G. Barkmann, Barkmann Engineering): Will you please give information on where the Caloria oil is available?

Question (Eric M. Wormser, Wormser Scientific Co.): Please give details on the heat-transfer oil, such as the supplier.

Question (Richard L. Field, USN Civil Engineering Laboratory): What is the name of the heat-transfer oil and whom is it made by?

Answer (in response to the three preceding questions): Caloria oil is available through your nearest large Exxon industrial distributor, or call (212) 597-8100.

Question (Mr. Wormser): Who is the supplier for the aluminum Roll-Bond® you used in the Madeira School?

Question (Richard L. Field, USN Civil Engineering Laboratory): Was the collector Dean Products Panelcoil or Olin Roll-Bond®?

Answer (in response to the two preceding questions): The material was Roll-Bond®, manufactured by Olin Brass Corporation, East Alton, Illinois 62024, telephone (618) 258-2000.

Question (Jose E. Ripper, Universidade Estadia de Campinas, Brazil): Is there any additional source of heat in the Madeira School?

Answer: Yes, an oil-fired hot water boiler.

SOLAR COLLECTORS AND THE MOBILE HOME

K. T. Stringer, Jr.
Mobile Homes Manufacturers Association
Chantilly, Virginia

The mobile home industry represents one of the largest and most immediate potential users of solar energy systems. Because of the uniquely innovative character of our industry, and because of the inherent ability of the mobile home to readily utilize solar energy systems, the problems confronting the application of solar energy to the heating and cooling of mobile homes are considerably fewer than those which face the implementation of solar energy systems by conventional, site-built housing. But the obstacles which remain are nonetheless significant, and may be just as difficult to overcome; their elimination can be accomplished only through the joint efforts of the experts in both the solar energy and the mobile housing fields. Hopefully, this conference will mark the beginning of such cooperation, and pave the way toward the development of a sound, efficient and highly marketable solar energy system for use on the mobile home.

By way of introduction to the mobile home industry, I should like to point out that in 1973, the mobile home accounted for over ninety percent of all single-family homes built to sell for under twenty thousand dollars. In the United States, today, there are almost four million mobile homes in use as primary dwellings, and each year this number continues to grow as conventional, site-built housing costs increase beyond the reach of many American families. Within the next few years, it is expected that the mobile home will become the principal source of low and moderate cost housing in this country.

Just as the need for such housing continues to grow, so does the need for more, and yet less expensive, energy. The projected energy needs of this nation for the next twenty years is a fact that cannot be ignored and much of these needs will take the form of the heating and cooling requirements of private residences. Every day we are made painfully aware of the fact that we cannot continue to rely on petroleum and other fossil fuels to the same degree that we have in the past, or still do today. For this reason, the development of new, alternative energy sources has become a high priority in both government and industry circles. Unfortunately, most of the energy alternatives being considered today pose serious and substantial problems of technology or economy, problems which remove the actual mass utilization of such energy sources to a point in time ten, twenty or more years in the future.

In this regard, it is perhaps fair to say that solar energy can be considered an exception to this rule. While holding the "brightest" promise in terms of meeting our long-range needs, solar energy also can provide substantial short-range benefits that are all too often overlooked. We should not forget that there is a place for auxiliary energy systems today, and that solar energy can and should be utilized in just such a capacity. When it is, the solar energy system will find one of its greatest potential users in the mobile home industry.

The modern mobile home is uniquely adaptable to the use of solar energy systems, especially in an auxiliary mode. With a few design modifications, most of which involve structural changes. and with some minor alteration of existing standards of construction, the typical mobile home could easily support the weight of a solar collector array, and small storage tanks. Moreover, the comparatively small area of a mobile home, as opposed to conventional housing, eliminates the need for a massive system, and can be heated or cooled with relative ease. Finally, since last year many manufacturers have voluntarily undertaken the task of making their homes more energy-efficient through the use of more insulation, better construction techniques and more rigid quality control practices, to name just a few.

But the problems associated with adaptation of the mobile home to a solar energy system, whether as a primary or even secondary energy source, are not the major obstacles to wide-spread acceptance or utilization of such systems. It would be nice if we really had to worry about what sort of guarantee we needed, since that would be the signal that solar energy is here to stay. Construction codes, as indicated above, also present little real problem, since their alteration is simply a matter of procedure, once a product, or an idea has been proven safe, effective and valuable. Weight and wind loads pose more serious problems, but ones which can nevertheless be resolved with little difficulty. Mounting configurations for collector arrays pose practically no problem at all, since different configurations might prove more effective under different circumstances and since certain performance standards would have to be met anyway. Finally the problem of collector performance, seemingly the greatest one of all, will possibly prove to be of little concern, once basic minimum standards are developed and adopted. But each of these obstacles, while minor in and of themselves, could assume monumental proportions when coupled with the single, most important concern of the potential solar collector users -- cost. And for the mobile home industry, cost is a particularly important element.

One of the primary attractions of today's mobile home is its extremely low cost, relative to other forms of housing. Any solar energy system designed for use on the mobile home must, therefore,

be priced within a reasonable proportion to the home itself, or the ultimate user -- the homeowner -- won't buy it, and the "middle man" -- the mobile home manufacturer -- won't be interested in featuring models with such equipment.

But at this point, variables come into play. Rising fuel or electricity costs, the increasing size of the mobile home, the possibility of a small, solar energy "farm" that is integral with a mobile home park and serves four or five individual homes, shortages of one sort or another, and even the desire to be less dependent on other forms of energy, all could play a part in creating a more acceptable climate of opinion in which higher costs for solar energy systems would be gladly absorbed today, for some form of relief tomorrow.

Needless to say, mobile home manufacturers will welcome any new idea, concept or product that will help sell their homes. But they also recognize the growing importance of energy conservation and the utilization of solar energy systems on mobile homes could accomplish this foremost goal, as well as enhancing the attractiveness of mobile housing. From the comments I have heard in the last two days, it appears that solar energy research and development is alive and well. I hope you will remember that the mobile home industry is alive, well and anxiously awaiting the results of your effort.

DISCUSSION

Question (Terence B. McSweeney, Clarkson College of Technology): What is the average lifetime of mobile homes, as this affects capital recovery?

Answer (K. T. Stringer, Jr., Mobile Homes Manufacturers Association): Recent durability studies strongly suggest that, with proper construction methods and materials (i.e., those required by MHMA under its Construction Standard ANSI A 119.1), the average mobile home should last 30 years, and possibly longer. Put another way, with proper care and maintenance, such as that normally accorded permanent housing by those who occupy it and/or own it, a mobile home can be expected to last as long as the conventional, site-built home receiving similar care and maintenance.

Question (Mr. McSweeney): How about common collectors for mobile home parks?

Answer: This is a very attractive and potentially promising mode for utilizing solar energy. Currently, however, there are no active plans to install such a common system, primarily because park development in general is at a low level, and because of what is still a prohibitive cost of the collector system itself, as well as the land on which it would be installed. The most interesting concept to me, personally, is one in which collector arrays are installed on each home within, say, a cluster of 5 or 10 homes, and the water storage and conversion facilities are common, located underground.

Question (Gary C. Vliet, University of Texas at Austin): The mobile home presently has weak codes in terms of energy conservation, such as insulation. What is the Mobile Home Manufacturers Association doing about codes–specifically insulation–in terms of making mobile homes more energy conservative so that solar energy for heating and cooling will be more attractive?

Answer: In January of 1974, the insulation standards for mobile homes were substantially increased so that the home would be made more energy efficient. Although I am not aware of any formal studies on the subject, I think it would be safe to say that, with the new standards, mobile homes are fully as energy efficient as conventional, site-built housing, and manufacturers are constantly seeking ways of improving the product in terms of energy efficiency.

Question (Robert W. Annis, Annis Electronics): In western Kansas, mobile homes appear to be the larger part of new housing, but they are high users of energy at extremely inefficient utilization. This is not compatible with solar methods. What is the answer?

Answer: Certainly, Kansas reflects a national trend insofar as the percentage of new housing being increasingly dominated by the manufactured home, but I cannot see why such homes should be any less energy efficient, or why they would use any more energy than conventional homes, unless they are manufactured by companies which do not belong to MHMA and therefore do not construct their homes to ANSI standards. Higher standards for insulation, coupled with continuous efforts to make the homes more energy efficient, will result in homes fully compatible with the requirements of solar energy systems.

Question (David Aronson, David Aronson Associates): What are the pros and cons on having solar heaters as a park service, supplying heat to individual homes?

Answer: On the pro side there are, of course, all the benefits of a solar energy system, plus the decreased problems of adapting the individual mobile home to such a system. Cost to the individual home owner would possibly average out the same or perhaps less, when compared with that of purchasing a home with a factory-installed solar energy system. But, again, the basic con argument is that four-letter word, "cost." A solar energy system will occupy land, and reduce the space available for sale or rental lots; in addition, the cost of development will be higher and must be borne initially by the park owner. To my mind the pros outweigh the cons, but I am not presently contemplating the development of a mobile home community.

Question (Charles C. Smith, Colorado State University): What is your view on distributing hot water to several mobile homes from a central supply?

Answer: I see no problems with a central hot water supply, so long as there is a sufficient supply and the water is always hot enough, whether it is to be used to heat air, or for washing, bathing, etc. If these problems are eliminated, and it is easier and more economical to utilize a central solar heating/cooling system, then that should be undertaken. Fortunately, I don't believe we have to face an either-or situation here; when the solar heating/cooling system technology irons out the last few remaining bugs, individual or central systems will be equally viable.

Question (Frank DeWinter, Altas Corporation): Do you think that the mobile home can be made energy effective in view of the 2-in.-thick walls commonly used, which restrict insulation thickness?

Answer: First, let me correct one thing. Two-inch walls may be commonly used somewhere, but not in mobile homes being built today. Many homes are being constructed with conventional 2 x 4 studs, and the ANSI standard requires at least 3-in. studs (and this is a *full* 3-in. stud, unlike the 2 x 4 which is not quite 2 x 4). Mobile homes being built today are capable of utilizing almost as much insulation as conventional site-built homes, and are, therefore, capable of being fully as energy efficient as such housing. With an ongoing program of energy conservation efforts, the manufactured-housing industry may soon surpass the conventional home in its ability to conserve and most efficiently utilize energy.

SESSION 10

WORKING GROUP REPORTS

PANEL ON

LIQUID COOLED

SOLAR COLLECTORS

November 22, 1974
7:30 pm to 10:45 pm

Shawn Buckley	Massachusetts Institute of Technology
Jack Cherne	TRW Inc.
Henry Chuang	University of Dayton
R. R. Davison	Texas A&M
Gene Drucker	Syracuse University
Stan Gilman	Penn State University
Harold R. Hay	Skytherm
Robert Liu	Agricultural Research Service US Dept. of Agriculture
Glen L. Merrill	Honeywell Inc.
John Minardi	University of Dayton
S. W. Moore	Los Alamos Scientific Lab.
William Robbins	W. R. Robbins & Son, Miami
R. L. SanMartin	New Mexico State University
Roger N. Schmidt	Honeywell Inc.
Fred Simon	NASA-Lewis Research Center
C. J. Swet	Community Technology, Inc.
Dan S. Ward	Colorado State University
Harold G. Lorsch Chairman	University of Pennsylvania

The Panel on Liquid Cooled Solar Collectors was unanimous it its praise of the technical excellence of the Solar Collector Workshop. Since the bulk of the work presented was funded under the NSF program this reflects favorably on that program. The panel wishes to express its appreciation to the organizers of the workshop and to the NSF personnel responsible for holding it and for running the solar heating and cooling program in general.

Considerable discussion on various facets of liquid cooled solar collectors took place. From what we understand the discussion was, at times, more heated than that occurring in other meeting rooms. However, in the end a general consensus was obtained, and the following items were singled out for special consideration.

1) The panel was not convinced that the "best" solar collector has been designed yet. Therefore it asks NSF to continue

to encourage innovative approaches to liquid cooled solar collectors.

2) Cost reductions can be obtained by integrating collectors into the structure of the building. Thus collectors would serve a dual function. Research into this aspect should be funded.

3) The panel spent a large amount of its time on a discussion of the problems of collector corrosion. In view of the somewhat conflicting data presented at the workshop it was felt that the subject deserves further clarification. To this effect the panel recommends: (a) Materials presently incorporated in solar collectors should be reviewed for corrosion resistance. (b) For those materials found to be non-resistant a search for methods of inhibiting corrosion should be undertaken. (c) Inhibitors should preferable be non-toxic.

4) In good conscience we cannot recommend the incorporation into a building of a component whose life span is unknown. To remedy this situation the panel recommends that: (a) Available information on the life of collector components should be collected. (b) Where the information is lacking, methods for obtaining the data should be developed; among these methods accelerated life tests should be considered.

5) The panel criticized the variety of reference data used by different researchers reporting on collector performance at the workshop. If this was felt to be confusing to a group of workers in the field, how much more confusing must it be to the public unfamiliar with solar heating and cooling? It is therefore recommended that NSF establish consistent standard units by which the performance of solar collectors shall be reported. Examples are: area (gross, net, window area, absorber area), efficiency (useful energy divided by total energy falling on the collector area), output temperature (absorber temperature, water exit temperature). These units should be established with participation by NBS and ASHRAE to ensure compatibility with data requirements of the building HVAC system.

6) In order to be able to judge the superiority of one collector over another collector meaningfully, collector performance should be related to function (heating, cooling, heating and cooling, domestic hot water), geographic location (latitude, ambient temperatures, cloud cover), type of user (residential, commercial), and life cycle cost.

7) Special components developed in the past, such as thermosyphons, should not be ignored under the NSF program. Attention should be paid to freezing problems, not only in thermosyphons, but in all solar collectors.

8) Insufficient solar data are available for the rational design of solar systems. NSF should actively encourage and support NOAA to obtain accurate data on solar insolation from a larger number of locations throughout the country.

9) To prevent operation of solar collectors under unsafe conditions, manufacturers should specify maximum operating pressures for their collectors. In accordance with the proposed NBS standards, collectors should be tested to 1 1/2 times that operating pressure. It should be the responsibility of the system designer to ensure that the specified operating pressures are not exceeded.

10) It is recommended that NSF consider funding projects on manufacturing techniques suitable for solar collectors as a method of stimulating the development of lower cost hardware.

REPORT OF THE WORKING GROUP ON SOLAR AIR HEATING COLLECTORS

by

M. Kudret Selçuk, PhD
Jet Propulsion Laboratory
Pasadena, California

The working group for the Solar Air Heating Collectors discussed various topics of interest, covering a broad range from the fundamental studies to the economics of solar air heaters. Devices and systems employed to heat air for space heating or agricultural produce drying purposes were discussed. Desiccant type cooling systems as well as absorption cooling via high temperature air were also discussed. Although much material has been presented during this workshop, covering various analytical, performance, production and economic features of liquid heating flat plate or concentrating collectors, only six papers dealing with air heaters and systems were presented.

It should be noted that the only system which has served continuously during the past sixteen years without a major breakdown is the solar heated house in Denver, Colorado.

A thorough survey into solar air heaters and their applications should bring answers to the following questions:

1) Why is solar air heating recommended?
2) Where should they be used?
3) How do we heat air most efficiently for a particular process?
4) How much do we spend and what are the benefits?
5) What should we be doing to make solar air heaters cost effective, practical and reliable?

The final answers to these questions obviously are not available. It would be unfair to expect the solution of such major problems within the time frame of the working group meeting.

In answering the first question, we have to define our objectives, then think of ways to achieve these objectives by employing air heaters. The speaker here apologizes for taking our time to express a few simple facts which are known by most of us:

1) Solar air heaters have no frost, fluid leakage, corrosion or runaway problems.
2) The working fluid costs nothing.
3) Solar air heaters require less maintenance than liquid heaters.
4) Solar collector design could be simpler, thus enabling significant cost reduction.
5) In some specific applications, such as space heating and agricultural drying, it is most reasonable to use the same fluid both for collection of heat and for the final process.

Space heating, which is a matter of survival for many cold, but sunny regions, has great potential of application and chance of public acceptance. Air conditioning on the other hand, would be the first thing to drop in case the utility bill exceeds the financial means of the occupant. Many residences already utilizing a hot air heating system could be retrofitted with minimum effort and expenditure. Therefore, the question "where do we use solar air heaters?" is partly answered since space heating and agricultural drying are two major applications which would have substantial impact on the national economy. It should be noted that in most of the mid-continent and southwestern United States the summer season is usually dry, which gives the opportunity of direct evaporative cooling. This application, which is still in widespread use in Arizona and neighboring states, has the most potential for the immediate future heating via solar energy. Field type solar dryers for agricultural produce have further advantages of combining the collector and dryer in one structure, thus minimizing the capital expenditure. Such demonstration schemes developed at the Brace Research Institute of McGill

University in Canada and this speaker at the Middle East Technical University in Ankara Turkey offers some immediate economical applications.

The answer to the question of how do we heat air and use it for the process in mind requires the study of

a) transport system

b) storage of heat

c) controls

Basic criteria of defining the ideal system does not necessarily consist of all the most efficient or inexpensive components; it is, rather, a combination of these components which yields the cost effective solution. This statement could be further clarified by expressing the fact that a less efficient collector might as well be used if it is inexpensive. The same facts apply to the transport system, storage media and-controls.

The heat transport system could be optimized by a careful analysis of duct dimensions, pressure drop and power requirements, insulation, and structural aspects by introducing the material and labor cost in addition to the fluid flow characteristics. The procedure of analysis is straightforward and presents no scientific challenges. It should, however, include the relative costs of the related components together with the cost of the transport system. Ducting and collector joints should be carefully sealed since air leakage, which is not readily visible, could result in major heat losses.

The thermal storage system, on the other hand, offers the alternatives of sensible and heat of fusion storage. Pebble beds which offer the simple design and low cost features require largest volume, whereas heat of fusion material demands the least. On the other hand, pebble beds have an infinite lifetime while problems related to heat of fusion materials, such as stratification, supercooling and encapsulation, are still being investigated. A major drawback of the heat of fusion material is its fixed melting point which limits the usable air temperature.

A controversial issue of using air to water finned heat exchanger must be given serious consideration. At least a thorough analysis of thermal and economic performance is recommended before settling on the pebble bed storage system.

Solar air heating systems could be simplified to a fan plus related ducting and a few dampers. Controls would be inexpensive and simple.

The major item in the solar air heater could be of two basic designs:

a) Conventional flat plate absorber. Most widely used arrangement with fins at the back and air flowing over the rear of the plate was discussed during the workshop session on solar air heaters. Optimization of the fin shape, size and spacing as well as the fluid flow to maximize the heat transfer and to minimize the pressure drop will be very significant in terms of shedding light on the heat transfer phenomena from the absorber plate and establishing guidelines to design cost efficient flat plate heaters.

b) Porous matrix air heaters, which cover a braod range from the perforated plate to wire mesh, or from slit and expanded metal absorber to honeycomb as tested by the UCLA team, deserve close attention.

Thermal and economic analysis of each type must be undertaken by considering the recent developments in the glass or plastic honeycomb fabrication technology and the present cost figures of the slit and expanded matrices. Among the ideas and actual experiments run are use of glass fibers, blackened wood shavings, or metal chips. The first one is not reported yet although this speaker has actually used wood shavings and metal chips during some drying experiments run in Ankara. It is admitted that the efficiency was low, but the cost of the matrix was nil. Thus, a compromise was reached in terms of cost effectiveness.

The following drawbacks should be borne in mind:

1) The porous matrix should not be clogged with the dust and lint in the

air stream, thus the pressure drop must be kept within permissible limits.

2) The heat losses resulting from the introduction of air from the upper side of the absorber matrix could become significant in case the air inlet gets significantly higher than the ambient.

Porous absorbers, on the other hand, offer less ΔP for the same CFM/ft^2 for a clean matrix than does the flat plate absorber with fins. The penetration of the radiation through the absorbing matrix and transfer to air stream at different layers, and smaller ΔT between the matrix and the air stream, resulting from large heat transfer surfaces per unit volume and increased turbulence, are among major advantages.

The collector box which encloses the absorber could be made of lighter gauge metal since the absorber would be of less weight. Experiments regarding the construction and lifetime of all plastic thermoformed boxes, fiber glass sprayed over the glass fiber mats, extruded plastic and all form glass boxes in addition to conventional steel or aluminum boxes and realistic mass production cost figures are desired. No plastic box has been identified by the panel members which would incorporate the proven features of low cost, long life and resistance to moisture and fire.

Among ideas brought out have been the use of metallic or paper honeycombs with proper impregnation although no cost data have been available.

The use of roof topping plywood for retrofitting purposes would reduce the box design to a layer of insulating material plus the edges to support the glass plates.

In conclusion, it is believed that solar air heating collectors deserve closer attention due to the reasons cited. Among various projects recommended for future R&D, in addition to those mentioned, are the survey of heat pipes in air heating collectors, further study of the fluid flow and heat transfer phenomena for flat

plate and novel porous absorbers utilizing techniques of flow visualization and I.R. thermometry, establish firm results of lifetime and cost predictions. The establishment of standards for operation and fulfillment of codes and legal requirements should be urged. The problems of solar air heaters are complicated and exceed the scope of any single specialist. Thermal sciences, materials, economics and production teams have to work in close cooperation at various stages of R&D and fabrication if cost effective and reliable designs are sought.

Last, but not least, the disclosure of failure and problems in any fabrication and operation effort as well as R&D is essential. This attitude will enable all of us not to duplicate the mistakes , to look for remedies to any defect before the consumer or supporting agency finds it! There is nothing worse than losing the confidence of the public we are obliged to serve as solar scientists and engineers.

REPORT OF THE

WORKING GROUP ON FOCUSING COLLECTORS

E.A. Farber, Chairman

A very enthusiastic group of 15 people met from 7:30 until 10:30 discussing the many aspects of focusing collectors.

It was brought out that for true and proper evaluation, good weather data is essential, and that it is necessary to have the relationship between direct, diffuse and total radiation. This is especially important when focusing collectors are to be compared to flat plate collectors.

The place where focusing collectors can make their contributions is in air conditioning, process heat, and total energy systems. Focusing collectors can be roughly classified as low, medium, and high concentration devices, with the most appropriate rating given as the cost per million BTU at a certain temperature and location. It was brought out that the cost per ft^2 of collecting surface is less for a focusing collector than for a typical flat plate collector.

The pedestal designs often used for small arrays are much too costly for large ones, so different designs are indicated. They can incorporate both moving collector or mirror surfaces and moving targets. While the tracking system may constitute an appreciable part of the total cost in small systems, in large ones it is negligible.

Many materials are available for reflective surfaces, with backsilvered glass at about $\$0.40/ft^2$ the old standby. Today, the other coatings and materials on the market should be investigated and considered. For low concentration, plastics such as aluminized polyester may be very satisfactory (ultraviolet-resistant Mylar, etc.). Dust, in most cases, reduces reflectance by only a few percent.

The design of the focusing collector target was discussed. Because of its small size, a cover glass in many cases is not needed to reduce losses (although this may depend upon the particular application). Selective surfaces do not seem to help much in most cases. Evacuated glass jackets can improve efficiency but also add appreciably to the cost.

In general, the group felt that focusing collectors had at least as much potential as flat plate collectors for cost-effective solar energy applications, and that therefore at least equal support should be made available for focusing collector development and evaluation.

DISCUSSION

Question (John A. Duffie, University of Wisconsin): There have been hundreds of thousands of practical solar energy delivery systems built, and they all utilize flat plate collectors. What new developments do you see that will permit this situation to change?

Answer (Eric A. Farber, University of Florida): The flat plate collector has been universally used because in the past we were interested in low-temperature applications. With more recent developments such as air conditioning coming in, some of the approaches will require higher temperatures. If you need higher temperatures and want to combine them with heating, then the concentrating systems have a good possibility of making an impact in the field. I believe there is a use for each of the devices, depending upon the particular application and what we intend to be fulfilled.

Question (Frank DeWinter, Altas Corp.): Whillier, in the 1967 ASHRAE report on solar energy application, says that the flat plate collector should be used for fluid temperatures less than 150° F above ambient, while the concentrating collector is appropriate for fluid temperature above that. Would you comment on this criterion, and on the work necessary to refine it?

Answer: The feeling in the group last night was that this criterion is not really applicable to the concentrating collector; that the results obtained by analysis of the concentrating type of collector do not quite agree with this analysis. Additional work is needed to get reliable data and comparisons.

REPORT OF WORKING GROUP ON

MATERIALS AND COMPONENTS FOR FLAT-PLATE COLLECTORS

J.A. Duffie, T. Hollands, J. Howell, J. Jurisson,
D.L. Kirkpatrick, J.D. Mackenzie, K.N. Marshall,
T. Santala, D.I. Tchernev, and
D. Waksman

Report of Working Group at NSF Collector Workshop, 11/22/74

The Working Group discussions are introduced by several general comments relating to all material and components, followed by a discussion of specific materials and components, and concluded with further generalizations.

I. General Comments on Materials

All materials and components for solar energy collectors should be designed to have adequate mechanical strength under the worst conditions to be expected in collector operation. Materials should be designed to withstand the maximum temperatures to be encountered during periods of high radiation and zero energy delivery from the collector. Temperature cycling, maximum equilibrium temperatures, and maximum temperature gradients must be taken into account in material selection and design.

Life time of components are important in determining cost of delivered energy, and corrosion may be a limiting factor (for example, corrosion of absorber plates and fluid passages). There appears to be no single solution to this class of problem; however, the use of best possible practice under the circumstances, to minimize corrosion and assure maximum life time is recommended.

It should also be recognized that collectors may operate in urban atmospheres with high concentrations of SO_2, H_20, oxides of nitrogen, etc. which may cause materials deterioration.

There exists a need for ready access of collector designers to useful and up to date information on corrosion and related material problems. There is a parallel need for good reliable methods of getting these data, for the unique situation encountered in solar energy collectors. (The suggestion was made that the Electrochemical Society might be a useful forum for this work.)

II. Selective Surfaces

There are several commercial selected surfaces now in use. These include copper black on copper (Australia), copper or nickle black on galvanized steel (Israel), and aluminum oxide on aluminum. There remain, however, needs for further developments in this field, to obtain higher absorptances, and possibly lower emittances.

The need for separate data on both absorptance and emittance was noted. The ratio of absorptance to emittance does not enter the energy balances describing the performance of collectors, and the ratio is not an index of the improvements in thermal performance to be expected from the use of these surfaces in collectors.

More recent research has dealt with nickel black on nickel, with the nickel substrate plated on steel or other base material, with surfaces having $\alpha = 0.95+$ and $\alpha = 0.07$. Durability appears to be a problem with these surfaces. Further work is being done on chrome black on nickel, which has similar α and ε and which may have better durability.

Intermetallic compounds, for example, AlNi, have highly porous surface structure, and which obtain their selectivity by virture of having pore structure of dimension of the same order as the wavelength of solar radiation. These surfaces absorb as cavities, yet radiate as flat surfaces. They may have properties such as $\alpha = 0.95$ and $\varepsilon = 0.3$. They may be very stable.

Other possibilities include application of antireflection coatings, finely divided semiconductors with organic binders (with the problem being in finding binders without high absorption in the IR) and shaped surfaces such as the groove collectors.

Lifetime of selective surfaces remains a difficult question. Initial values of α and ε may degrade with use. Some measurements on selective collectors have indicated increases in ε on long term use. This degradation may be caused by ultraviolet radiation on the one hand, or effects of atmospheric components such as moisture on the other. There is need for quality control, both in the processes of manufacturing selective surfaces and in determination of the properties. There is a need for both screening measurement and precise measurements. There is need for development of instruments for this purpose (particularly for screening measurements) and their intelligent use.

Cost estimates of selective surfaces now range in the general area of 50-75¢ per square foot for services of current or potential interest. There is some speculation that cost might get as low as 10¢ a square foot.

In summary, the full story is not in on selective surfaces, their cost and the benefits to be derived from them. The possibilities remain interesting and it is an area worth further substantial work.

III. Honeycombs

In contrast to selective surfaces, the benefits in thermal performance to be derived from use of Honeycombs between plate and cover (or cover and cover) are not well defined. Honeycomb has four possible effects on performance.

Presence of honeycomb in spaces over the absorbing surface can have an effect on the transmittance of the cover system. At normal incidence, the effects may be small. At increasing angles of incidence, it becomes increasing important to use honeycomb materials having minimum absorption for solar radiation. On this basis, transparent honeycombs will probably absorb less radiation then reflecting honeycombs and should, on balance, show better properties.

Convection suppression represents the major objective of honeycomb. If the Rayleigh number is below the critical value, most convection is probably eliminated. This will require L/D ratio greater than about four. The positioning of the honeycomb relative to the absorbing plate (and cover) is thought to be not critical, but this question is now being studied.

If temperature gradients are established outward along the honeycomb from plate to cover, some reduction in hemispherical emittance of the system for long wave radiation may result. This effect will probably be small with temperature gradients of the magnitude to be expected in flat plate collectors.

Conduction through the honeycomb material itself may represent a appreciable contribution to thermal loss from plates to cover, if the honeycomb is thick. (It may be necessary for honeycombs to be thick, for reasons of mechanical strength and thermal stability.)

The net effect of all of these factors is not yet established nor are costs of honeycombs. This remains an interesting field for research, and one which may result in improved collector performance.

IV. Cover Materials

Several possible methods are available for modifying or replacing the most commonly used glass cover on flat plate collectors. It is possible to improve the transmittance of glass by treating its surface to reduce reflectance (by an HF acid etch). This etching process, which was developed in the 1940's, removes calcium and oxygen from the surface layers of the glass and creates a porous structure of refractive index intermediate between that of unetched glass and air. There may be mechanical stability problems with these surfaces. It is also possible to apply antireflective coatings to glass (or plastics) to reduce surface reflections.

At the same time, it is possible to increase the reflectance of glass for long wave radiation above its usual value of about 0.12. Such an increase would have an effect similar to a selective surface in reducing radiation transfer from plate to cover or cover to cover. A primary problem with these coating processes is that those produced to date have resulted in diminution of the solar transmittance of the glass to an extent which more than offsets gains due to increased long wave reflectance.

Plastic materials may be used for covers, for the possible reason of cost reduction, impact resistance or weight reduction. Materials such as Tedlar and Lexan are among possible candidates for solar collector applications. Plastic materials may have limited life time, usually have partial transmittance for long wave radiation and may be unable to withstand the maximum equilibrium temperatures to be encountered in collectors. However, there are potential applications, particularly if UV stablizers can be developed which will result in lifetime long enough for amortization of the investment in the collectors.

V. Insulation

Insulating material may provide part of the structure of collectors, should have appropriately low value of thermal conductivity, and must be thermally stable at the maximum temperatures to be encountered. If a collector is to be mounted as a integral part of the building in such a way that the insulation on the back of the collector would be contained within the weatherproof structure, questions such as the possibility of emission of gases on overheating will have to be resolved.

VI. General Comments

In closing, several comments of a general nature may be made regarding materials.

Most of the materials discussed by the working group did not seem to present potential problems of shortage of supplies. However, this question should be checked with any material which would have to be used in large quantities in collectors.

The suggestion was made that convenient means are needed to predict the potential usefulness of innovations in collector materials, to see whether or not an innovation would be worth pursuing in view of the cost incurred in the innovation and potential benefits in thermal performance be gained by it. It may be that numerical models of collectors, or analytical methods, may yield ready answers on this question. (An example has been provided in selective surfaces, which show under most conditions of application that α is more critical then ε.)

These various materials may each have effects on the thermal performance of collectors, but these affects are clearly not additive. The interdependence of these effects must be recognized by proper consideration of the energy balances that describe the operations of collectors. Thus for example, an infrared reflecting glass cover would have less potential effects on the performance of the collector with a selective surface than one with a nonselective surface.

Finally, the value of these innovations will depend in large measure on the application to be made of the collectors, and more specifically on the temperature level at which the collectors may operate. Thus a selective surface might be cost-effective in one application, and not in another.

JAD

STATEMENT OF WORKING GROUP ON NUMERICAL MODELING

E.A. Astiz, R.B. Bannerot, W.A. Beckman (Chairman),
P.A. Curto, P.O. McCormick, J.W. Ramsey,
S.L. Sargent, R.J. Schlesinger and
P.R. Smith

The easiest thing for the numerical modeling group to agree upon was that numerical modeling is useful. However, it must be remembered that all members of the working group were modelers. The group had some difficulty separating collectors models from system models. The chairman attempted to direct the discussion towards collector models but it is recognized that many collector models are inseparable from system models.

At least two levels of modeling was identified. The first level includes detailed models that are useful in the design of a particular collector. These detailed models are often necessary to understand the consequences of various design choices whereas simplified models may not be useful for detailed design.

Detailed models are not particularly useful to anyone except the originator as they are usually directed towards specific application. The group agreed that it does not appear feasible or desirable to generate a general numerical model for use by everyone. Someone interested in a detailed model is better off to generate his own model which he fully understands and which is directed towards answering his specific questions. Since many people have generated numerical models, some discussion revolved around a comparison of these various models. The working group did not believe that an intercomparison of these various models was necessary. The validity of any mathematical model can only be checked against experiments.

Systems analysis models can and should be much simpler then design models. A model such as proposed by Hottel, Whillier and Bliss correctly predicts performance behavior for most collectors of "standard design". There are notable exceptions. For example, through flow collectors such as the matrix type or the Löf overlap glass plate type and high heat capacity systems such as the thermal trap collector cannot be put in a simple form. Collectors with a modest amount of heat capacity can be adequately described by the Hottel-Whillier-Bliss model as pointed out by Klein, et al.*

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*Klein, S.A., Duffie, J.A., and Beckman, W.A., "Transient Considerations of Flat-Plate Collectors," ASME J. Engr. Power, 96A, 109 (1974).

Basic data is lacking for use in both detailed models and simplified models. A major problem still exists in finding basic free convection transfer data between parallel flat plates. The available data at present is concerned almost wholly with vertical systems or horizontal systems. It is recognized that inclined systems are now being given attention. Free convection in different geometrics also appears to be important. For example, free convection from a Vee-grove cavity to the cover plate has never received any attention. In order to better understand some of the open channel type solar collectors some fundamental work needs to be done with combined free convection and mass transfer. The group agreed that basic studies of convection suppression need to be continued. The forced convection problem from the outside surface of collectors has not received adequate attention. For single cover collectors the outside heat transfer coefficient plays an important role in determining the collector efficiency.

One other major piece of information is sorely lacking for adequate numerical models. Solar radiation data is extremely difficult to obtain and the group suggests that NSF sponsor a program to prepare data tapes for use by all interested parties. These revised data tapes could be obtained from weather service tapes that are currently available. The difficulties with these tapes is that they have not been screened for errors, they are not in any easy to use format, and some of the data is on one tape and other data is on the second tape.

DISCUSSION

Question (H. Mahon, University of Massachusetts): Would it be useful to obtain additional data on collectable heat under ambient weather and pollution conditions in northern cities?

Answer (William Beckman, University of Wisconsin): If you mean, should a collector be used to determine "collectable heat," I think the answer is no. What is necessary is reliable meteorological data on a much broader scale than currently available.

Question (Mr. Mahon): Are the characteristics of the Pittsburgh Plate Glass (PPG) collector well enough known to enable data collected to be related to other collectors?

Answer: The PPG collector is of a standard design and should therefore be amenable to analysis. Consequently, I do not believe it would be a worthwhile exercise to compare one collector with the measured performance of another collector.

REPORT OF THE WORKING GROUP ON TESTING AND STANDARDS

John I. Yellott, Chairman

1. The multi-disciplinary Task Group on Testing and Standards met on Friday evening, November 22, to consider the general subject of testing solar collectors and the specific subject of the November 1 version of the N.B.S. Proposed Standard Method of Testing for Rating Solar Collectors based on Thermal Performance. The Task Group was composed of Messrs Hill and Streed of N.B.S.; Messrs Keeling and Rauch of Motorola and Ortabase of Corning Glass Works (representing industry); Mr. David Hartman of Dubin-Mindell-Bloome (consulting engineers); Mr. Richard Vernon (NASA-Lewis Research Center); Mr. David Lee (A.D. Little); Mr. Charles Smith (Colorado State Univ.); Professors F.H. Morse (Univ. of Maryland) and J.I. Yellott (Arizona State University).

2. The Task Group first considered the purpose and probable use of solar collector test results and its attention was immediately directed towards the relative usefulness of day-long and instantaneous (i.e. 15 minute) tests. It was agreed that each would have its field of usefulness for the designing engineer, but that in most parts of the country, day-long tests would be very difficult to obtain.

Carefully conducted tests of 15 minutes duration, as outlined in the N.B.S. document of November 1, 1974, were considered to be essential to the relative evaluation of different types and designs of collectors and to determining their suitability to perform specific tasks.

Among the questions considered by the Task Group were the effects of the variation of the incident angle between the sun's direct rays and the line normal to the collector plane and the ratio of diffuse to direct radiation. The matter of determining the longwave radiation exchange between the cover plates and the sky was discussed but this was left as an item of unfinished business, preferably to be the subject of additional careful study.

3. Dr. Hill, the principal author of the N.B.S. document, asked how the results of the proposed tests would be used and by whom. The consensus of the group was that the industry needs such a document for at least three purposes:

(a) to determined whether a given collector can actually perform a particular task under a specific set of conditions.

(b) to compare the performance of several competitive collectors under comparable conditions.

(c) to give the designing engineer adequate information with which, in conjunction with the ASHRAE clear day hourly insolation and incident angle data, would enable him to make reliable estimates of problable clear day performance of the tested collector.

It was agreed that it would be helpful to add to the literature an addendum to the proposed standard in the form of suggested means of using the test data for estimating probable collector performance on monthly and yearly bases, using actual Weather Bureau Data.

4. There was a protracted discussion of the identification of the precise area on which collector efficiency should be based. It was finally agreed the the area (A_a) to be used in calculating the efficiency by means of Equations (1) and (2) on p. 17 of the Nov. 1 edition should be the area of the transparent frontal surface for flat plate collectors and the aperture area for concentrating collectors.

5. The subject of wind speed limitations was also discussed at length and since there is good authority (St. James, Ch. 8, vs 6) for the statement: "the wind bloweth where it listeth and no man knoweth whence it comes or whither it goes", the best solution was simply to measure the wind direction and velocity at the collector test site (see p. 35, Nov. 1 ed.) and report these data among the test conditions.

6. In response to the question of normalizing the variables which are given on the abscissa (X-axis) of the efficiency vs temperature difference/insolation plot, it was suggested that the insolation could be made dimensionless by dividing it by the solar constant, 1353 w/m^2; the temperature difference term could be made dimensionless by dividing the actual value by the interval (180 F or 100 C) between the freezing point and boiling point of water. The value of such normalization was questioned, however.

7. As to the choice between S.I. and "customary" units, it was agreed that both sets should be used in each case and, for the sake of consistency with the Nov. 1 document, the S.I. units would be given first, followed by the "customary" units in parentheses. It was cautioned that the "customary units" must invariably be given because HVAC engineers are not yet sufficiently familiar with S.I. units for them to be widely used. The matter of the space required for extensive tables (i.e. pp 30-33 of the Nov 1 edition) was discussed at length and the most expedient solution in the case of tables which are already printed in Btu/(hr. sq. ft.) is to use a bold-faced footnote stating that the tabulated values should be multiplied by 3.15 to obtain the equivalent values in mw/cm^2.

8. In response to the third specific question which had been put to the Task Group, asking what insolation should be used in computing the efficiency of a tracking (sun-following) collector, it was recommended that the pyranometer to measure that insolation should be mounted on the plane of the tracking collector. Its output, with appropriate corrections for the tilt angle and its possible effect upon the pyranometer calbration, should be used in the efficiency determination just as the output of a fixed pyranometer in the plane of a stationary collector would be used in determining its efficiency.

9. In response to the fourth specific questions, adequate ASHRAE standards exist for the determination of the solar-optical properties (i.e. transmittance, reflectance and absorbtance) of cover plates and similar transparent or translucent materials. Standards are needed, however, for determining the performance of selective absorbtion surfaces when they are new and after they have undergone varying periods of service.

10. With reference to the frequency and methods of calibrating solar radiometers, the Working Group expressed the hope that the status of the calibration of pyranometers and pyrheliometers would soon be clarified and that

adequate facilities would be made available for accurate and impartial calibration of the large number of instruments which will soon be in use. Concern was expressed over the variation in pyranometer response with tilt angle and the hope was expressed that an appropriate agency, preferably the Bureau of Standards, would investigate and report on this situation with an authoritative publication. The only recent data were obtained in Australia and they include only one modern U.S. pyranometer.

11. The Task Group heartily commends Dr. James Hill and his colleagues at N.B.S. for the production of an eminently useful, readable, and literate document.

SESSION 11

SOLAR ENERGY PROGRAMS IN FEDERAL AGENCIES

GSA'S SOLAR DEMONSTRATION PROJECTS

M. RAY WHITLEY, PE
PUBLIC BUILDINGS SERVICE
GENERAL SERVICES ADMINISTRATION

Mr. Arthur F. Sampson, Administrator of General Services, sees our mission as much more than a real estate operation to provide office space. He feels that the Federal Government should exercise leadership in the construction industry -- leadership by example. Two GSA demonstration projects are examples of this leadership. Each project will include a large experimental solar energy installation.

Let's talk first about GSA's new building planned for Saginaw, Michigan. This building was designed as an environmental demonstration project. It's design includes an 8,000 square foot solar collector plus many other environmental features.

I'd like to tell you very briefly about some of the other innovative features of the design before getting into details of the solar collector.

- -- This will be a new building which, in effect, creates a park for residents and visitors with planting around the building and also on the roof.
- -- Automobile parking (117 spaces) will be located on two-thirds the building roof and thus hidden from view from the surrounding streets and sidewalks.
- -- The parking area on the roof has been designed as a play area for neighborhood children after hours.
- -- Full window walls are provided on one side of every block of office space to provide an open vista to outside.
- -- Recycled materials will be used in construction.
- -- Water consumption will be greatly reduced. The design provides for the collection and use of rain water for lawn irrigation. Also, toilet waste system will recycle the flushing medium.
- -- Energy-efficient design is accomplished through: low heat gain/heat loss through walls, most of which are protected by earth beams; dual glazed windows protected from summer solar load by large overhangs; low heat gain/heat loss through roof, one-third of which will have earth fill and planting; low-wattage lighting system; utilization of heat pumps having a high coefficient of performance for HVAC; and no requirements for elevators.

Now a few words about the solar collector.

It will be a flat plate collector, 40 feet high by 200 feet long. The collector and the associated energy environmental system were designed by Smith, Hinchman & Grylls of Detroit, Michigan, Architects/Engineers for the project, who utilized Dr. Erich A. Farber of the University of Florida as a consultant for the design of the solar collector.

The collector as currently designed is a non-modular unit which will require field assembly of the collector components. It utilizes a copper collector plate with formed water passages and a two layer glass cover. It will operate with water as the heat collection medium. It has been designed to be aesthetically pleasing, perform well, and withstand weathering for many years.

The energy from the solar collector will be stored as hot water in two separate 15,000 gallon insulated tanks. The low energy tank will receive solar heated water when it is collected in the 70-85 degree FAH temperature range and the high energy tank will receive solar heated water when it is collected in the 86-185 degree FAH temperature range.

The building HVAC utilizes a closed loop heat pump system which will draw energy from the solar heated water during the heating season and also has the capability of transferring heat from interior zones to exterior zones.

The Saginaw Building was entered in the 1974 Annual Progressive Architecture Awards Program by the Architect/Engineer and was awarded a design citation. The building was also entered in the Owens-Corning Fiberglas Energy Conservation Awards Program. This building was announced the winner of the Governmental Division at a banquet here in New York less than a week ago.

We are quite proud of this award winning building design. We are sure it will provide a good place to work and also make a positive contribution to the community. Further, much can be learned during the evaluation of the performance of the solar collector and other innovative features.

Let's move on and talk about the Manchester Project. This building was designed as an energy conservation demonstration project. The design includes a 4,600 square foot solar collector. Before describing the solar energy collector, I'd like to briefly list some of the energy conservation features.

-- Building configuration, orientation, fenestration including shading; insulation; wall mass, etc., have all been selected to reduce the energy required to operate the building.

-- Different HVAC Systems are provided on various floors to permit direct comparison of performance and efficiency. All systems included are expected to be energy efficient.

-- Various arrangements of unitary closed loop water-to-air- heat pumps are utilized for HVAC on floors 1 thru 3.

-- The HVAC for floors 4 thru 7 is provided by two central chillers and by 4 modular boilers with various types of distribution systems to the different floors. One central chiller is driven by a gas engine generator. The second central chiller is of the absorption type which operates from the waste heat from the engine generator.

-- Chillers are deliberately undersized in relation to the peak load. They will be operated at night when the electrical load is light and production of chilled water is more efficient. Stored chilled water, produced at night, will be used the next day during peak load period.

-- Various low-wattage lighting systems will be provided on the different floors to permit direct comparison of performance and efficiency.

-- The multiple environmental system in the building make it truly a real world laboratory.

Now a brief description of the solar collector and its interface with the building HVAC systems. The 4,600 square foot collector will be the modular, flat plate type mounted on the building roof. The solar energy system was designed by Dubin-Mindell-Bloome Associates, working as consultants to Isaak and Isaak, Architect-Engineers for the project.

The panels will be mounted in a four row saw-tooth arrangement. The supporting frame will be manually adjustable to permit varying the tilt angle as the height of the sun varies with the seasons. The large storage tanks for hot and for chilled water are required for the energy--saving building HVAC Systems and will also be used in conjunction with the solar energy system.

The construction of the Manchester Project is well underway. It is being constructed in three phases. Phase 1, consisting of the excavation and foundations, is just being completed. A contract for Phase 2, building superstructure, was awarded on November 22, 1974. Phase 3 for the solar collector will be delayed as long as practical to take advantage of advances in the state-of-the-art. However, we expect the entire building to be complete in June 1976, including the complete solar energy system.

Since both the Saginaw and Manchester Buildings include many innovative or experimental features, a full performance evaluation is planned after the occupancy of each building.

We expect the Manchester Project to operate with 40 to 50 percent less energy than comparable modern buildings subjected to the same climatic conditions. Already arrangements have been made with the National Bureau of Standards to make the performance evaluations. Both NBS and FEA are providing support for this evaluation effort and NSF funding for the solar collector panels is anticipated.

GSA is also currently looking into the possibility of retrofitting existing buildings to utilize solar radiation as a supplementary energy source. Some of this work will be done in conjunction with NASA and HUD.

How far does GSA expect to go with solar energy? The ultimate goal of GSA is to routinely incorporate solar energy systems in Federal office buildings, where determined feasible.

DISCUSSION

Question (Harold S. Lewis, Consulting Engineer): What is the gross floor area of the Saginaw building, and of the Manchester building?

Answer (M. Ray Whitley, General Services Administration): The Saginaw Federal Office Building will have a gross area of 59,500 ft^2 and the Manchester Federal Office Building will have a gross area of 175,000 ft^2.

Question (William J. Murphy, Revere Copper & Brass): On the Saginaw building, by whom was the selective coating for the collector surface developed, and are data available on its cost and longevity?

Answer: The surface finish planned for the copper collector plate is silicone-modified alkyd resin paint, formulated for high-temperature application and flat black in color. Data are not available on its cost and longevity.

Question (Richard LaRosa, Hazeltine Corporation): How is the Saginaw building collector drained to prevent freezing?

Answer: The collector design, with unrestricted vertical water passages for the full height of the collector, permits easy and complete draining into a tank within the building to prevent freezing.

Question (Paul T. Roth, New York City Environmental Protection Administration): How will the problems of oil, grease, dirt, and rock salt on the dual purpose roof-top area (parking during working hours and play area afterhours) on the Saginaw building be overcome?

Answer: Although [the roof-top is] not normally used as afterhours play areas, GSA is already faced with the problem of keeping the parking surfaces clean on numerous exterior and basement parking areas. We expect the problem to be only marginally more difficult when the surface is used for play in addition to the normal passage to and from personal and motor pool vehicles.

Question (Jeffrey Cook, Arizona State University): Can you point out the exterior energy-saving concepts visible in the Manchester building?

Answer: The exterior walls have been designed with a U value of approximately 0.06 to reduce the heat gain or loss through the walls. Further, the exterior walls have a mass of approximately 100 lb/ft^2, thus providing bulk for thermal storage to dampen the normal diurnal temperature swings. Windows comprise only about 15 percent of the east, west, and south walls. Fixed horizontal and vertical fins on the exterior wall surface break up the flow of wind along the wall. They also provide shading of the windows in the summer while permitting some direct solar radiation through the windows in the winter when the path of the sun is much lower. Windows are double glazed and effectively gasketed. The north wall of the building has no windows; elevators, mechanical rooms, duct shafts, and toilets are located adjacent to this wall.

SOLAR ENERGY PROGRAMS IN THE FEDERAL ENERGY ADMINISTRATION

Robert R. Jones, P E
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Federal Energy Administration
Washington, D.C. 20561

I can, perhaps, help you with your departure schedule, because my presentation is extremely short. I have not come up here to become an expert regarding solar collector panels, nor to impart any expertise regarding solar collectors.

My purpose in coming here is to share with you information on the areas where the Federal Energy Administration interfaces with people of your background and knowledge, and to relate how this will impact upon our main goal which is energy conservation.

For background, I am aprofessional engineer and I am fascinated by what I have heard today. Probably one of the greatest luxuries that I could have indulged myself in would have been attendance at all the sessions you have enjoyed here.

As far as the Federal Energy Administration goes, our principle task is not in the field of technology to which you have been exposed during this Workshop. It is related to policy research, development, and demonstration. But we are interested in getting solar installations working so that they conserve energy. You want to get them working; we want to conserve energy.

I have a very brief list of programs. Some of them are directly related to this, others may be a little off base, but you can see that the thrust of our program really is to remove constraints that keep solar energy from being exploited or implemented more and, in some instances, find incentives that will help it to be implemented.

One project that we have in the planning phase is to demonstrate an energy conserving single-family dwelling utilizing total energy system powered by solar energy. This will involve a low energy house, a low energy submerged structure and a commuter vehicle, complete with high temperature collectors and high temperature storage. Conceivably, we will be utilizing a Sterling engine to generate power and to drive the commuter vehicle. This is a

rather massive program, and at the present time, FEA is funding the planning overall staging of this program.

Later on, we hope that with seed money we can start a retrofit house that will have a Sterling engine in it. We will be working with the National Bureau of Standards who will have a comparable engine in their laboratory. We will be looking to other agencies and other organizations to fund other phases of this program. Planning has been done by the Naval Weapons Center, China Lake.

The second project is one that Mr. Whitley mentioned, in which GSA, NBS and FEA are working together. In this one, FEA participated in the funding of the instrumentation for the Manchester, New Hampshire Federal Building in order to permit the monitoring and analysis of energy conservation concepts, including solar energy.

We are currently working with the National Bureau of Standards in evaluation of solar water heater systems in a detached house, some townhouses, and some mobile homes, on the site and in the laboratory at the National Bureau of Standards, Gaithersburg.

We have supported a monthly abstract of energy policy research, which is handled by Oak Ridge Laboratories.

We are now considering a proposal to improve the electric utility load factor and reduce usage requirements for peak energy by use of specific systems and devices, which will include solar energy concepts. This proposal was submitted by the State of Arizona and their Public Utilities Service Commission.

One more activity that FEA engages in thru the Office of Energy Statistics is the identification of energy data requirements and the preparation and publishing of reports on all aspects of energy information. This information is now being presented to Congress on a regular basis, and provides Congressmen with information they did not previously have. The Office of Energy Statistics directs the activities of the National Energy Information Center, and serves as a clearing house for energy information sources.

The Nuclear and Solar Division is currently developing a data system that will monitor all aspects of the solar energy field. The data system will track all Federal and

private activities with regard to all aspects of solar energy. The division will analyze the supply and demand for solar energy and estimate current and future requirements. And, as of next week, this group will be coordinating with the Department of Housing and Urban Development in their charge to develop a data bank as part of the Solar Heating and Cooling Act of 1974.

DISCUSSION

Question (George B. Cain, Copper Development Association, Inc.): What incentives for solar energy systems are you recommending? What is the reaction of other Administration officials?

Answer (Robert Jones, Federal Energy Administration): FEA has not made "recommendations" on incentives to the President or the Congress. What we have done is to develop for consideration several "options" that indicate what impact is expected if certain incentives were to be implemented. We believe that tax credits and cash rebates will be considered by the Congress.

Question (Robert Liu, U.S. Department of Agriculture): Federal buildings should include greenhouses throughout the country. Solarization and environmental control of such buildings are important conservation practices. What programs and support can be expected from the General Services Administration and Federal Energy Administration?

Answer: At the present time we have nothing going in this area, and what will happen in the future I cannot predict. If there is an interest in it, I would certainly be interested in talking to anyone who would like to bring it to our attention and who would have some input to us so that we could perhaps develop some output. I don't know if I speak for Ray Whitley, but I think that their interest in greenhouses is probably parallel to ours, and their knowledge and participation right now is about the same.

Comment (M. Ray Whitley, General Services Administration): I have nothing to add to that.

THE PUBLIC TECHNOLOGY PROJECT PROGRAM

A. J. Schwarzkopf
National Science Foundation
Washington D.C.

The program for the Solar Heating and Cooling of Buildings being implemented by the Public Technology Projects Office (PTPO) is best explained by its budget.

The main effort of the program is being implemented through Phase Project Planning outline in Figure 1. The Phase 0 program was awarded to General Electric, TRW, and Westinghouse and has been completed. In general, the results and recommendations of the final Phase 0 reports were similar.

A summary of the Phase 0 results is outlined in Figure 2. The request for proposals for system definition for the follow on Phase 1 program is to be released shortly as already announced in the Commerce Business Daily.

The system definition studies and sub-system research efforts will utilize about 25% of the total funding.

The program will continue a number of projects started earlier. These include the five school projects. Four of these have already been reported. The fifth, the Atlanta school project, is now underway. The George A. Towns Elementary School is 32,000 sq. ft. in area and flat-roofed. The solar energy system will include a roof-mounted solar collector of about 10,000 sq. ft. to provide hot water for heating, cooling and for domestic hot water requirements. Thermal storage of 24,000-gallon capacity will carry the heating system through several cloudy days, and the cooling system for several hours.

The existing school boiler will back up the solar energy system for both heating and cooling, if and when required. The goal is to meet 60% of the heating and cooling needs of the school with the solar energy system.

The cooling system will be an ARKLA 100-ton absorption chiller, made by the Arkla Engineering Company, Evansville, Indiana.

The flat-plate solar collectors will heat water to a temperature between 160° and 250° Fahrenheit. Each collector module consists of an absorbing plate and two layers of tempered glass which are mounted in a stainless steel frame. The layers of glass insulate the collector plate from the outside air temperature.

Each collector plate is about 32 inches by 74 inches, providing more than 16 sq. ft. of collector area. The approximately 600 collectors will be manufactured by Pittsburgh Plate Glass (PPG) Industries, Inc. Honeywell, Inc. is supplying controls. The lithium-bromide absorption air conditioner operates directly from hot water at a temperature between 200 and 245 degrees Fahrenheit.

PTPO will continue to support the Transportable Solar Laboratory, currently moving about the country.

PTPO is also seriously considering the continued support of the solar assisted water heater project initially awarded to the Southern California Gas Company of Los Angeles as a planning grant.

As a result of the planning grant, the Southern California Gas Company has made the preliminary determination that solar assisted water heaters are more economical on a life cost basis than their gas fired counterparts in multi-unit dwellings. As a result of this, it has funded JPL to develop the specifications and requirements for multi-unit dwelling applications. Figure 3 shows the solar collector for a ten-unit simulation system developed at JPL as part of its study. The simulator uses approximately 400 sq. ft. of collector area.

The Southern California Gas Company now proposes to install two systems into the multi-unit dwelling complex, shown in figure 4, one during new construction and another as a retrofit. NSF is considering the support of all instrumentation and analysis required to analyze this application and the studies of utilization and policy alternatives necessary to develop a business plan that would provide a formula to foster similar solar systems by any utility or business entity.

Continuing projects will use about 20% of our yearly budget.

Another 25% will be spent on special system projects such as the City of Santa Clara project, "Solar Heating and Cooling as a Public Utility." This project, just awarded this month, will provide about 70 to 75% of the total energy requirements for the Community Center shown in its current state of construction in Figure 5.

Figure 6 shows the architects concept of the completed 27,000 sq. ft. building which will have 6,500 sq. ft. of collector area on rear and south facing roofs.

The solar system design which is being developed by the Lockheed Palo Alto Labs will utilize a black nickel coated copper collecter panel.

Cooling is to be provided by three 25-ton Arkla water chillers. The System will have a 10,000-gallon hot water and a 50,000 gallon chilled water storage capacity. A gas-fired boiler will provide supplementary energy when required.

The City of Santa Clara is also to develop a utilities blueprint for the implementation of the use of solar energy as an alternative energy source for public utilities. Santa Clara is in a good position to undertake such a study because the City acts as its own electrical utility; it is the largest member of the Northern California Power Agency (an eleven member group of cities that buy and distribute their own electrical power) and the City Manager, who is also the Principal Investigator, is a Director of the American Public Power Association (APPA). APPA is also participating in the project.

About 15% of our funding will be in support projects with other Federal Agencies such as the GSA Manchester and Saginaw Federal Office Building projects reviewed earlier.

The last area, Agricultural Applications, will use over 15% of our funds for solar applications in crop drying, livestock housing, and the heating and cooling of greenhouses and residences. The Agricultural Research Service of USDA will have the lead role in formulating agricultural program plans. Initial funding for crop drying has resulted in ARS awarding seven grants in areas of the mid-west for the drying of corn.

ARS is currently implementing a relatively new, low-temperature corn drying process which requires less than a 10° rise above ambient in drying air temperatures. Providing the heat for this process by solar energy is a natural combination. Even better, this is a solar energy application that can easily be expanded next season and will assist another world-wide problem -- FOOD.

Figure 7 shows a normal storage bin used in conjunction with the University of Illinois for the low-temperature drying process. The unit attached to the bin is for heating and blowing the required air volume through the stored corn.

Figure 8 shows the bottled source for the heat supply for the previous pictured bin. The bin in this picture has an additional bin wall installed at the outer edge of the roof overhang, for half of the bin facing south. This outer wall is spaced from the innerway by 2x4 blocks forming a plenum area. One of the air entrances formed by the outer wall is shown.

Air travels in both sides and is drawn into the chamber covering the blower and in turn is blown into the bin of Figure 9. As the air travels inside the false wall heated by the sun, it picks up the 5 to 8° required to do the job. Crude? -- Yes. But it does the job with equipment the farmer has and is familiar with and AT LOW COST. If more heat is required, make the outer wall of a transparent plastic and paint the bin's normal wall black. IT WILL WORK.

Another approach being developed by a small firm is shown in Figure 10. The Helio unit uses a 100' black plastic tube to create heat. A 1/2 h.p. motor blows air though the inner black tube as shown in Figure 11, inflates the system, and feeds the hot air into the bin. Air leakage inflates the outer tube.

The day this picture, Figure 11, was taken, it was 50° outside and the solar system was providing air at 85°. The material cost of this system is about $200.00.

PHASED PROJECT PLANNING

NATIONAL SCIENCE FOUNDATION	PHASE 0 --	ADVANCED RESEARCH AND SYSTEMS ANALYSIS
	PHASE 1 --	SYSTEMS DEFINITION AND SUBSYSTEMS EXPERIMENTS
	PHASE 2 --	SYSTEMS PROOF-OF-CONCEPT EXPERIMENTS
USERS	PHASE 3 --	DESIGN AND DEVELOPMENT OF OPERATIONAL SYSTEMS
	PHASE 4 --	PRODUCTION AND OPERATION OF SYSTEMS

Fig. 1 – NSF/RANN Project Plan for Solar Heating and Cooling of Buildings

MAJOR STUDY CONCLUSIONS AND RECOMMENDATIONS

- SOLAR HEATING AND COOLING OF BUILDINGS IS TECHNICALLY FEASIBLE TODAY
- LARGE DOLLAR MARKET BY YEAR 2000 ($1 BILLION/YEAR)
- PUBLIC INTEREST HIGH; NO MAJOR INFRASTRUCTURE PROBLEMS FORSEEN
- CAPITAL COST REDUCTIONS WILL PERMIT EVEN GREATER CONVENTIONAL ENERGY SAVINGS
- DEVELOP LOWER-COST INTEGRATED DESIGNS USING HEAT PUMPS DURING PHASE I
- IMPLEMENT NATION-WIDE PROOF-OF-CONCEPT EXPERIMENTS INVOLVING A TOTAL OF 54 BUILDINGS IN SIX CITIES DURING PHASE II

Fig. 2 – Summary of Phase O Results

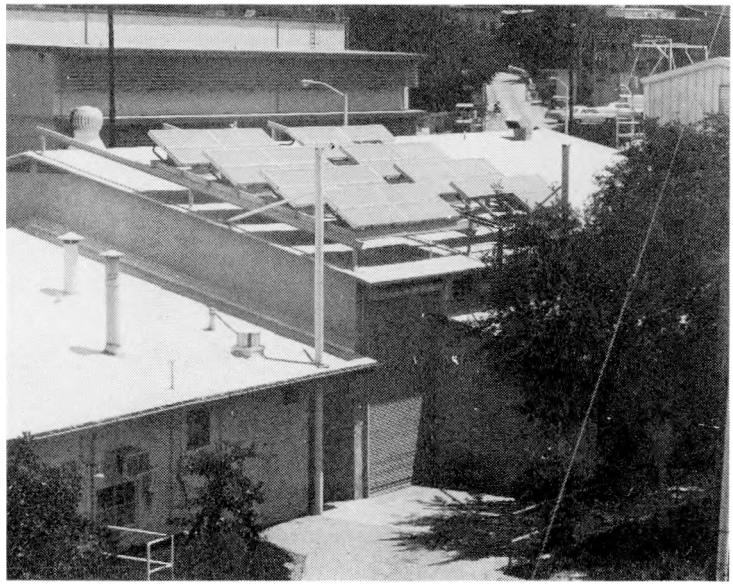


Fig. 3 – Collector Array at Jet Propulsion Laboratory for Simulation Study of Ten-unit Apartment Solar Water Heating



Fig. 4 — Apartment Complex Selected for Solar Water Heating Supply

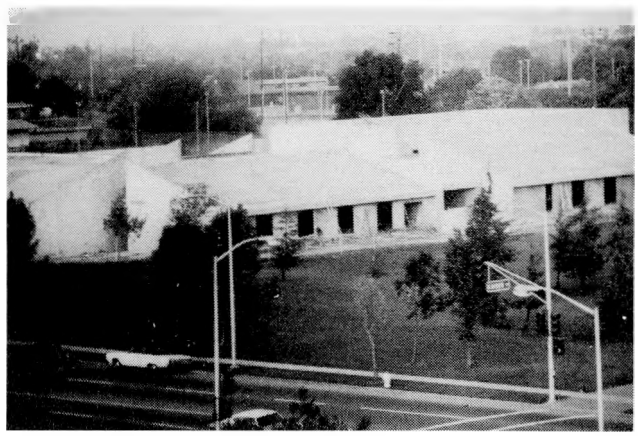


Fig. 5 — Santa Clara Community Center Under Construction



Fig. 6 — Architect's Concept of Completed Santa Clara Community Center, Showing Collector Arrays



Fig. 7 — Typical Corn Storage Bin

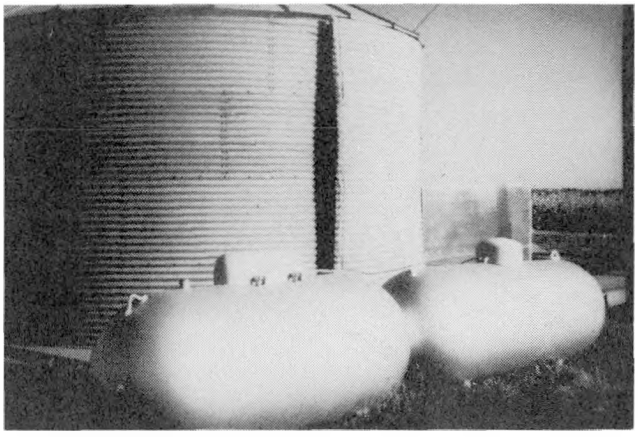


Fig. 8 — Bottled Gas Tanks for Corn Storage Bin

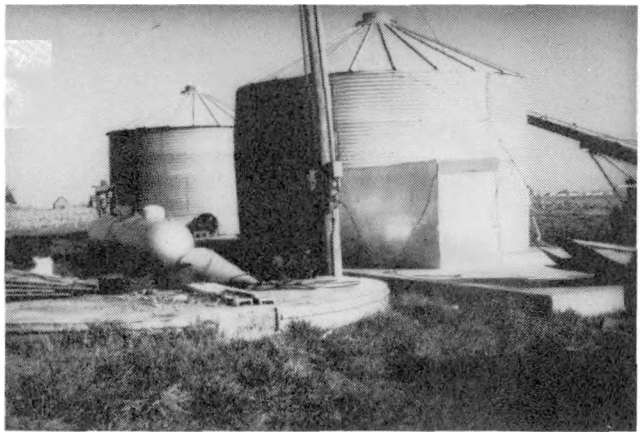


Fig. 9 — Corn Storage Bin with Bottled Gas Tanks

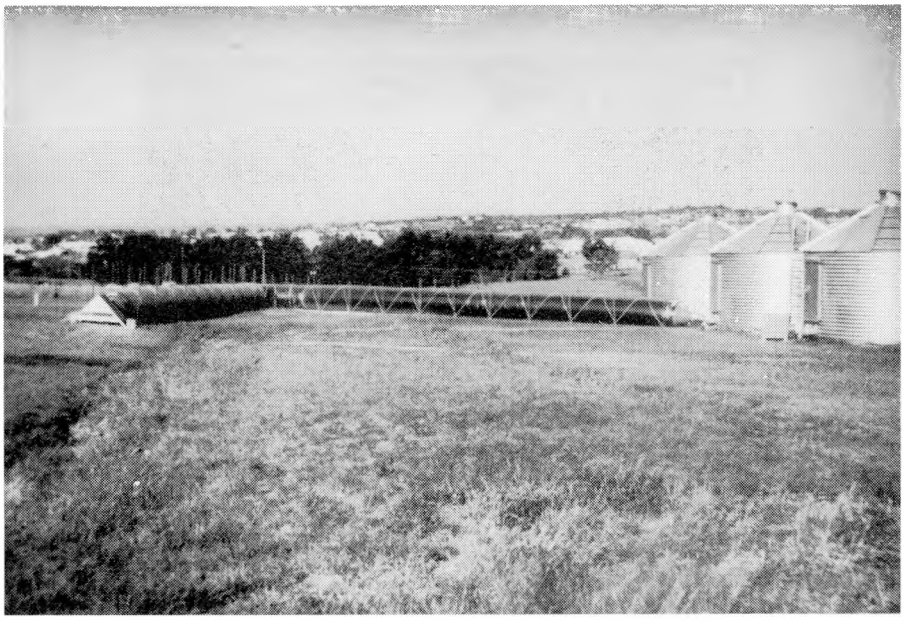


Fig. 10 — Tubular Plastic Air Heating Collector for Corn Drying

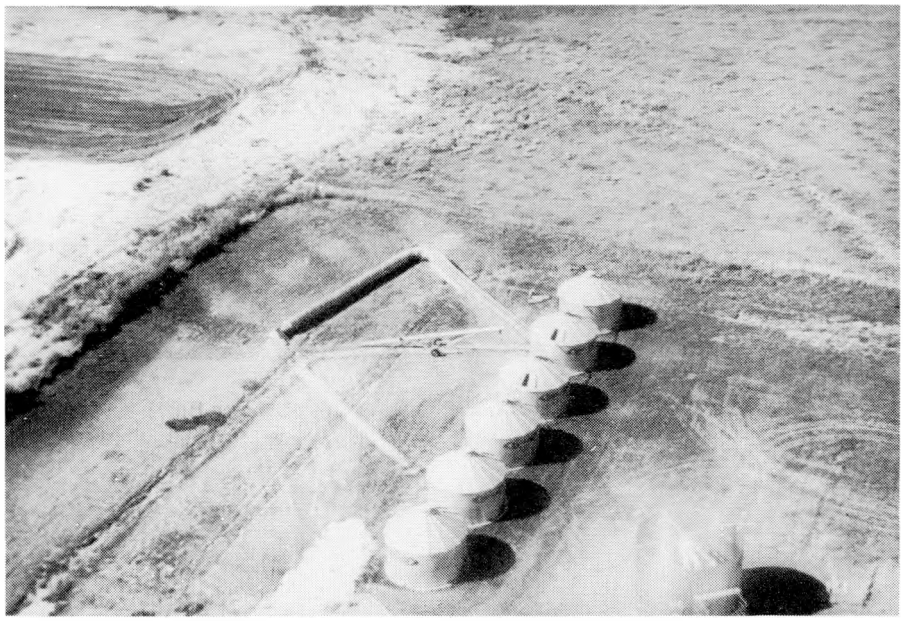


Fig. 11 — Layout of Tubular Plastic Collector

OVERVIEW: NSF PROGRAM FOR ADVANCED SOLAR ENERGY RESEARCH AND TECHNOLOGY

By
Lloyd O. Herwig
Director, Advanced Solar Energy Research and Technology
Division of Advanced Energy Research and Technology
National Science Foundation
Washington, D. C. 20550

I will not attempt to give an overall, comprehensive review of what the research and technology program will be. There just is not time. I'll make a few remarks.

First, the workshop: I think that this meeting of people together to exchange information and to find out who is doing what and to get the most recent results is an extremely valuable thing to have happen fairly often.

The point, I think, that needs to be emphasized is that we are still only at the beginning in a lot of ways. Most of the projects that you heard about that are being sponsored by NSF and that were reported on at this conference are projects that have only been under way a few months. The number of projects that have been going for a year or more is probably less than ten. There are about 30 that have been going just a few months. The results that you hear, hopefully, are favorable and indicate that we are making some progress.

But I think the real impact of what is happening here is down the pike about another year when these projects start putting out information that will be very beneficial to the whole enterprise.

My estimate is that, over the last five years, considerably less than $10 million has been expended in heating and cooling projects and research--perhaps closer to $5 million. That's not a trivial amount of money, of course, but it's still, in the scheme of energy research, not a great deal of money.

I would estimate that by the end of the year research will be underway at the rate of about $10 million a year. This will result in a growing volume of useful information.

Our estimates of funding by industry and universities and other institutions working on solar energy projects or research or whatever, is as much as three to five times higher than the Federal funds being provided. This calendar year we have some indications that spending by industries, universities and individuals on solar energy activities might be in the range of $25 to $50 million.

The Federal funding allocated for FY 1975 is about $17 million for heating and cooling of buildings, including agricultural applications.

I might mention that the whole program is funded at about $50 million this year. There are some perturbations that seem to be rising on the horizon that could reduce that figure.

We believe that additional funding needs to be applied to all of the solar research and technology areas. I might just briefly point out

that the project area that Alex has just told you about and the area that I represent, which is Research and Technology, are, in a sense, two separate organizations within NSF. They do not report to the same director, but our offices are geographically adjacent to each other. It is, of course, necessary that you understand what we consider to be a project and what we consider to be research and technology so that you can come to the right group. Even if you make a mistake, you'll be steered right very shortly.

Basically, the projects area is trying to take technology that is "state-of-the-art" and get it out into an applications area. Application areas are selected to have the greatest impact and nearest-term payoff. Projects are undertaken to show that present systems work, to get performance data, to get some initial inputs on social, environmental and other impacts effecting the systems, and then to communicate this information as rapidly as possible to the users and researchers and everybody else so we can get a good feedback going.

Under research and technology, we try to provide information that can improve even the state-of-the-art systems.

Perhaps more importantly, we are looking to improved components, subsystems, systems, and to new concepts and ideas to be explored for advanced systems, which will be included in the next generation of experiments. However, we certainly don't put any sharp distinction between first generation and second generation systems at this particular stage. This difference will be a bigger factor as the solar heating and cooling demonstration act of 1974 is implemented since the systems to be implemented for heating are going to have to be selected very shortly.

The criteria for selection of systems for demonstration are being developed now. The planners will not want to take large risks in demonstrating substantial numbers of unproven systems.

They must begin by sorting out what is available to implement as state-of-the-art and what is pushing a little too hard and can result in very uncertain results. In that way, the implementation of the heating and cooling demonstration act of 1974 will be a definition of what is state-of-the-art and what is second generation.

The objective of the research and technology program is to develop improved systems and thus to make first generation systems obsolete as rapidly as possible. That is the watchword of what we hope to be funding in the way of research and technology projects. Could I add something

about a program solicitation that is coming from NSF very shortly in an area which is much removed from research and technology.

It is a program solicitation to develop studies of social, legal, institutional, and incentive areas of heating and cooling of buildings. Not necessarily just heating and cooling of buildings--across the board in solar energy--but the real impacts and the majority of the projects will probably relate to heating and cooling of buildings.

Incentives are a topic of broad interest to industrial producers, to users, and everybody else. Congress is very interested in the kind of incentives that should be implemented. There is not much in the way of background information or study results to guide policy in these various areas. I expect that discussions of these policies and studies to understand the possible impacts will proceed simultaneously and, we hope, fruitfully.

If you are interested to be involved in this program solicitation, I would ask you to call the program manager who will be managing this, whose name is Mr. Larry Rosenberg. He is associated with the Division of Advanced Productivity Research and Technology at the NSF.

COMMENTS ON THE SOLAR COLLECTOR WORKSHOP

by

Hoyt C. Hottel
Professor Emeritus
Department of Chemical Engineering
Massachusetts Institue of Technology

Because of his long experience in solar energy research and development, Professor Hottel was invited to attend the Solar Collector Workshop, and has prepared the following comments.

Comments of H.C. Hottel

on

Workshop on Solar Collectors for Heating and Cooling of Buildings

In many of the presentations, particularly those related to specific installations of collector systems, there was either an absence of economic realism or a presentation designed to hide valid economic conclusions which borders on being inexcusable. Such harsh words demand explanation.

When a device or system is in so preliminary a state of development as to defy exact description and its development promises enormous economic gain but is full of unsolved problems, the application of economic constraints is quite inappropriate; it can dry up the enthusiasm of researchers, prevent further development which might greatly improve economic viability. Even when a nearly final form is taken by the system, if one of the steps in its production makes an enormous contribution to fabrication cost without using much expensive material, then there is legitimate hope for changing the fabrication technique; and failure to recognize economic limitations is still a justifiable--though dangerously near ostrich-like--attitude.

But are solar collectors in this category? They have been sold commercially for decades in industrially advanced societies for hot-water heating under conditions such that cost reduction would benefit the seller—in Israel, Australia, Japan, Florida (even in California in the early 1900's, before oil). Their mode of operation is so well understood that competent engineers can predict the effect of design changes with high accuracy. They are made of standard materials with the fabrication of which we have had much experience - glass, plastics, insulation, piping, metals, and surface preparation. When solar collectors are in that category any research or developmental effort on them should not be judged the way breeder reactor research is evaluated; it is time to narrow our concept of what price range makes them economically viable, and time to identify that range in our discussion of the implication of results. Perhaps the layman is not ready to pass on the economic viability of public-building solar collector systems (though I think he is). But the engineer is certainly able to do so, and should be given the opportunity. If the architectural and engineering design of an installation is such that, by passing a

miracle the solar collector is obtained free and the system still does not pay for itself, then the project should be labeled as standing for judgment purely on its educational or aesthetic merits.

The Nation is on the eve of accumulating an enormous amount of design data and, later, of performance data on space heating and hot water supply from solar energy. Unless guidelines are set in advance, the economic analysis of these data will take almost as many forms as there are authors of reports. Some of the different sets of data will be comparable, some will not; but correlation will go begging if we don't standardize. The object of the next few paragraphs is to suggest a method of presentation which covers adequately the question of how well solar energy utilization for space-heating and hot water supply is developing toward economic viability.

It is proposed that the only performance data necessary for economic assessment of most solar heat installations are a number and a curve or tabulated function. The number, q_o, is the year-average rate of energy collectible by unit area of collector, say therms/ft^{2}yr., independent of the associated system's ability to make effective use of the energy. (It may be necessary to report q_o at each of several collector plate or feed-water temperatures; two should in general suffice). q_o measures the combined effects of solar climate, outdoor air temperature, and collector design; it will vary from 1 to 2 therms per square foot per year. Higher numbers are possible but they often do not survive close scrutiny.

The other physical information necessary is the measure of utilizability of the heat collected. Let the annual usable energy requirement be E. The area to supply it would be E/q_o if every Btu collected could be used, and the fractional annual fuel saving R associated with a total area A would be Aq_o/E. R will in fact be this value when it is small, but as more area is added the utilizability of energy collected goes down increasingly due to too much energy collected in the summer or, even during the heating season, to high sunlight at times when the storage system is filled. The relation between R and Aq_o/E is somewhat like the following:

R	0	0.1	0.2	0.30	0.40	0.5	0.6	0.7	0.8	0.9	1.0
q_oA/E	0	0.1	0.2	0.32	0.44	0.58	0.74	0.92	1.18	1.55	x

x = positively excessive

(the equality of R and Aq_o/E extends to higher R as the fraction of the year's energy needs which is due to hot water supply increases, or as the size of the storage system increases; the table is characteristic of a too-large storage system; more than 18 pounds of water per square foot of collector can seldom be justified). It is understood that the relation given in the table must come either from step-by-step calculations based on weather collector design, storage system size, the thermal characteristics of the space to be heated, and the hot water needs; or a single point on the curve can be obtained from experiment, along with an establishment of the initial slope. The R vs Aq_o/E relation is the needed one referred to above. The inverse ratio E/Aq_o may properly be called the utilizability of the energy collected.

To show that q_o and the R-Aq_o/E relation, plus cost data, suffice to make an economic appraisal, let the assumed cost be formulated. Let ϕ represent the fractional fixed charge on capital, including interest,repairs, and depreciation (different subscripts could be appended to indicate values for different capital items, but will not). The cost items will be:

Fuel Cost, (1-R)EF,		where F is the unit cost of fuel, dollars per therm if E is in therms per year.
Fixed Charge on Solar System exclusive of collectors	$C_s\phi$	where C_s is the capital cost of solar piping, storage tank, insulation, controls, pumps.
Fixed Charge on Collectors	$C_cA\phi$,	where C_c is the capital cost of <u>installed</u> collectors,per unit area

The fixed charge on the furnace and portion of the heating system which is conventional is omitted, since it is common to solar and non-solar systems. From the above,

$$\text{Total annual cost exclusive of charge on conventional part of system} = (1 - R)F\,E + C_s\phi + C_c\,A\phi \qquad (1)$$

The optimum area of collector is of course obtained by setting the derivative of cost with respect to collector area equal to zero.

$$\frac{d(\text{Cost})}{dA} = 0 = -EF\, dR/dA + C_c\phi \qquad (2$$

$$\text{or} \quad dR/dA = C_c\phi/EF$$

$$\text{or} \quad dR/d(Aq_o/E) = C_c\phi/Fq_o \qquad (3$$

If the point of tangency of the line of slope $C_c\phi/Fq_o$ to the curve* represented by the tabulation above is called $(Aq_o/E)_{opt}$, the total annual cost is given by

$$\text{Total Cost exclusive of conventional parts of system} = (1-R)EF + C_s\phi + \left(\frac{Aq_o}{E}\right)_{opt} \frac{C_c\phi E}{q_o} \qquad (4$$

This is an old story to many engineers; to some it is more nearly general than conventional treatments by virtue of having been put in dimensionless form to make intercomparisons easier.

As a numerical example, let

E = 1000 therms/year (modest-sized home)

q_o = 2 therms/year per square feet

ϕ = 0.1

C_c = 5(or 8) \$/ft^2

F = \$0.40/therm, corresponding to oil at 40¢/gal, burned with an efficiency of 70%.

Then $C_c\phi E/q_o$ = 250(or 400). The slope $C_c\phi Fq_o$ equals 5/8(or 1), and this is tangent to the tabulated function at Aq_o/E = 0.7(or 0.2) and R = 0.57(or 0.2).

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* If $C_c\phi/Fq_o$ is greater than the maximum curve slope (at R=0), no collectors are warranted even if the main solar system cost C_s were zero.

The annual cost, exclusive of charges on the conventional part, is

For $5 collectors:	fuel	$172,	basic solar system	$60,	collectors	$175,	Total	$409
For $8 collectors:	"	$320,	"	"	"	$60,	"	$ 50,	"	$430
For Conventional system:	"	$400,						"	$400

The object has not been to identify numbers (though q_o = 2 therms/ft^2 per year exceeds the expectations of a two-glass collector in Lexington, Mass. unless a selective surface is used; and the R-Aq_o/E relation is generous but reasonable) but to indicate a method. We deserve to see every solar space-heating or hot water system that is constructed with our tax dollars described in terms of its q_o and its estimated R-vs-Aq_o/E relation. Then those combinations of values of collector unit cost C_C, solar system cost C_S, unit fuel cost F and fixed charge ϕ that make economic sense become apparent.

In the report on the solar installation in the Dorchester, Mass. school, a maximum delivery of 169 Btu/ft^{2}hr, maximum daily total for the system of 4.5x10^{6}Btu, and a maximum efficiency of 50% were reported. These numbers impress the listener but do not tell him the performance.

The Timonium school installation includes a collector guaranteed to perform poorly by virtue of the bare water layer over the collector surface. This is a built-in thermal leak having no place in good collector design; water vapor is formed at the plate surface and condenses on the glass above it.

Despite the critical comments that have preceded, many of the reports of progress were impressive. The reporting of some of the service experience was particularly valuable - pacifying aluminum surfaces; finding what kinds of joints leak; identifying the temperature fluctuation along the glass cover, toward its edges, which produces thermal stresses in the glass; radiator hose inadequacy; epoxy inadequacy.

Here are some random comments: The suggestions of reexamining hot-air collection and storage systems for space-heating and of devising cheap crop-drying techniques look attractive. Some of the results reported on selective black coatings looked particularly promising; the data from NASA on the subject were especially informative. It is difficult to find a better word than "premature" to characterize full-scale experiments with photovoltaic cells on a house roof. It will be interesting to watch the outcome of the

contest between selective-surface flat plates and cheap low-concentrating systems for producing heat at temperatures somewhat above that needed for space-heating. Anyone concerned with the lack of realism exhibited in projections of flat-plate collector costs has even more reason for concern in the area of focusing systems. The presentation of performance data and costs of plastic warm-air heaters was refreshingly realistic. A number of relatively new ideas deserve consideration; examples are the thermic diode, zeolite for space cooling; placement of selectivity on the glass rather than on the absorber surface. Economic viability of space heating is still far enough away to justify extensive low-level support of new ideas.

NSF/RANN WORKSHOP ON SOLAR COLLECTORS
FOR HEATING AND COOLING OF BUILDINGS

The New York Hilton Hotel November 21-23, 1974

PROGRAM

THURSDAY, NOVEMBER 21, 1974

8:30-8:45 AM	Welcome and Opening Remarks: Lloyd Herwig, Division of Advanced Energy Research and Technology, NSF/RANN
Session 1	FLAT PLATE LIQUID HEATING COLLECTORS Chairman: Charles Chen, Office of Public Technology Projects, NSF/RANN Facilitator: Jeffrey Rauch, ASME Solar Energy Div.
Part A	
8:45-9:00 AM	Performance of the Fauquier High School Solar Heating System: George Szego, Inter-Technology Corp.
9:00-9:15	North View High School Flat Plate Liquid Heating Collectors: Glenn Merrill, Systems and Research Center, Honeywell Corp.
9:15-9:30	Solar Collector Design and Performance Experience for the Grover Cleveland School: Don Kirkpatrick, Energy Engineering, General Electric Corp.
9:30-9:45	Flat Plate System Operation and Economics for the Timonium Elementary School: Irwin Barr, AAI Corp.
9:45-10:00	Experimental Evaluation of Flat Plate Collector Configurations: James Ramsey, Systems and Research Center, Honeywell Corp.
10:00-10:15	The Colorado State University Solar Heated and Cooled House: Dan Ward, Solar Energy Applications Laboratory, Colorado State University
10:15-10:30	Coffee Break
10:30-10:45	Questions and Discussion on Session 1, Part A
Part B	
10:45-11:00 AM	Structurally Integrated Steel Solar Collector Development: Stanley Moore, Los Alamos Scientific Lab.
11:00-11:15	Compressed Film Floating Deck Solar Water Heater: Richard Davision, Engineering Experiment Station, Texas A & M University
11:15-11:30	Glass Solar Heat Collector Development: Roger Gillette, Research and Engineering Division, Boeing Aerospace Corp.
11:30-11:45	Evaluation of the Solar Building, Albuquerque, New Mexico: Stanley Gilman, Dept. of Architectural Engineering, Pennsylvania State University
11:45-12 Noon	Questions and Discussion on Session 1

Noon-2:00 PM	Lunch Break
Session 2	FLAT PLATE AIR HEATING COLLECTORS Chairman: David Hurdis, Dept. of Mechanical Engineering, University of Maryland Facilitator: Barton Turkington, ASME Solar Energy Div.
2:00-2:15 PM	Long Term (sixteen years) Performance of an Overlapped-Glass Plate Solar Air Heater: John Ward, Solar Energy Applications Laboratory, Colorado State University
2:15-2:30	Space Heating with Solar Air Collectors: George Löf, Solar Energy Applications Laboratory, Colorado State University
2:30-2:45	Solar Collectors of "Solar One": Tuncer Kuzay, Institute of Energy Conversion, University of Delaware
2:45-3:00	Heat Pipes Applied to Flat Plate Solar Collectors: Walter Bienert, Dynatherm Corp.
3:00-3:15	Flat Plate Solar Air Collectors for Agricultural Use: Jack Cherne, TRW Systems
3:15-3:30	Project Sungazer: A Vertical-Vaned Flat Plate Collector with Forced-Air Heat Transfer: John Keyes, International Solarthermics Corp.
3:30-3:45	Coffee Break
3:45-4:00	Questions and Discussion on Session 2
Session 3	FOCUSING COLLECTORS Chairman: James Dally, Dept. of Mechanical Engineering, University of Maryland Facilitator: Frank DeWinter, Altas Corp.
4:00-4:15	Compound Parabolic Concentrator: Vaclav Sevcik, Argonne National Laboratory
4:15-4:30	Development of Solar Heat Supply System with Fixed Mirror Concentrators: J. Richard Williams, School of Mechanical Engineering, Georgia Institute of Technology
4:30-4:45	A Solar Powered Steam Supplement for Heating and Cooling of Buildings: J.G. Cottingham, Brookhaven National Laboratory
4:45-5:00	Cost Effective Focusing Collector for Solar Heating and Cooling: Irwin Barr, AAI Corp.
5:00-5:15	Modeling and Construction of the Stationary Reflector/Tracking Absorber Solar Collector: Jan Kreider, Environmental Consulting Services, Inc.
5:15-5:30	Economic Considerations for Focusing Collectors: Frank Kreith, Dept. of Chemical Engineering, University of Colorado
5:30-5:45	Questions and Discussion on Session 3
5:45-7:30	Dinner Break

Session 4 PANEL DISCUSSION BY COLLECTOR MANUFACTURERS

Moderator: Harold Horowitz, Division of Advanced Energy Research and Technology, NSF/RANN

Facilitator: Terry Hollands, ASME Solar Energy Div.

Opening Presentations

7:30-7:45 PM	Frank Bauer, General Manager, Beasley Industries Pty. Ltd., Adelaide, South Australia
7:45-8:00	William Robbins, Jr., Owner, W.R. Robbins and Sons Roofing Co., Miami, Florida
8:00-8:10	Al Jenkins, President, Energex Corp., Las Vegas, Nev.
8:10-8:20	R.R. Lewchuk, New Products Development, PPG Industries, Inc., Pittsburgh, Pennsylvania
8:20-8:30	Harry Thomason, President, Thomason Solar Homes, Inc., Washington, D.C.
8:30-8:40	Everett Barber, President, Sunworks, Inc., Guilford. Connecticut
8:40-8:50	Freeman Ford, President, FAFCO, Inc. Menlo Park, Ca.
8:50-9:00	William Heidrich, Building Products Dept., Revere Copper and Brass, Inc., Rome, N.Y.
9:00-9:15	Coffee Break
9:15-10:30	Questions and Discussion on Session 4

FRIDAY, NOVEMBER 22, 1974

Session 5 COLLECTOR MATERIALS AND COMPONENTS

Chairman: James Eibling, Battelle Memorial Institute

Facilitator: Redfield Allen, Dept. of Mechanical Engineering, University of Maryland

8:30-8:40 AM	Corrosion Protection for Aluminum Solar Energy Collector Plates: Sheldon Butt, Roll Bond Products Div., Olin Brass Corp.
8:40-8:50	Intermetallic Absorption Surfaces - Material Systems for Collector Plates: Teuvo Santala, Texas Instruments, Inc.
8:50-9:00	Selective Flat Plate Collector Coatings: Henry Mar (Presented by Jaan Jurisson), Systems and Research Center, Honeywell Corp.
9:00-9:10	Experimental Radiative Performance of Moderately Concentrating Solar Collectors: John Howell, Dept. of Mechanical Engineering, University of Houston
9:10-9:20	Studies on Methods for Reducing Heat Losses from Flat-Plate Solar Collectors: K.G.T. Hollands, Dept. of Mechanical Engineering, Univ. of Waterloo
9:20-9:30	Transparent Glass Honeycombs: John MacKenzie, School of Engineering and Applied Science, UCLA
9:30-9:40	Development of a Flat Plate Solar Collector Using Transparent Plastic Honeycombs: Kenneth Marshall, Lockheed Palo Alto Research Laboratory
9:40-9:50	Solar Energy Cooling with Zeolites: Dmiter Tchernev, Lincoln Laboratory, MIT.

9:50-10:00	Thermic Diode Solar Panels: Shawn Buckley, Dept. of Mechanical Engineering, MIT
10:00-10:15	Coffee Break
10:15-10:35	Questions and Discussion on Session 5

Session 6 NUMERICAL MODELS

Chairman: Alex Schwarzkopf, Office of Public Technology Projects, NSF/RANN

Facilitator: Frederick Morse, Dept. of Mechanical Engineering, University of Maryland

10:35-10:45 AM	Collector Modelling: James Ramsey, Systems & Research Center, Honeywell Corp.
10:45-10:55	The Thermal Collector Model in the University of Pennsylvania Solar Heating/Cooling Electric Power System Computer Simulation Program: Martin Wolf (presented by Harold Lorsch), National Center for Energy Management and Power, Univ. of Pa.
10:55-11:05	Lockheed-Huntsville Solar HVAC Simulation Model: Paul McCormick, Huntsville Research and Engineering Center, Lockheed Missiles & Space Corp.
11:05-11:15	Hybrid Simulation of Solar HVAC System for House Retro-fit Design: Robert Schlesinger, Rho Sigma Unlimited
11:15-11:25	Moderately Concentrating (Not Focusing)Solar Energy Collectors: Richard Bannerot, Dept. of Mechanical Engineering, University of Houston
11:25-11:35	Numerical Modelling of Thermal Trap and Water-Trickle Solar Collectors: Phillip Smith, Dept. of Mechanical Engineering, New Mexico State Univ.
11:35-11:45	The Hottel, Whillier, Bliss Collector Model: William Beckman, Solar Energy Laboratory, University of Wisconsin
11:45-12 Noon	Questions and Discussion on Session 6

12:15-2:00 PM Luncheon and Address by Congressman Mike McCormack

Session 7 TESTING AND STANDARDS

Chairman: John Yellott, College of Architecture, Arizona State University

Facilitator: Robert San Martin, ASME Solar Energy Div.

2:00-2:20 PM	Proposed Method of Testing for Rating Solar Collectors Based on Thermal Performance: James Hill, National Bureau of Standards
2:20-2:30	Solar Collector Testing and Standards: Noam Lior (presented by Harold Lorsch), National Center for Energy Management and Power, Univ. of Pa.

2:30-2:40 PM	A Brief Review of Material Property Measurements for Solar Collector Components: Elmer Streed, National Bureau of Standards
2:40-2:50	Development of a Performance Specification for Solar Collectors: David Hartman, Dubin-Mindell-Bloome Assoc.
2:50-3:00	Solar Collector Testing by Calorimetry: David Lee, A.D. Little, Inc.
3:00-3:30	Questions and Discussion on Session 7
3:30-3:45	Coffee Break

Session 8 NASA AND HUD SOLAR ENERGY PROGRAMS

Chairman: Robert Miley, Div. of Advanced Energy Research and Technology, NSF/RANN

Facilitator: William Beckman, ASME Solar Energy Div.

3:45-4:00 PM	Program Plan for Solar Heating and Cooling Demonstration Act: Joe Sherman, Office of Policy Development and Research, Dept. of HUD, and Ronald Scott, Office of Energy Programs, NASA Headquarters
4:00-4:15	Questions and Discussion on the Program Plan
4:15-4:30	Overview of Solar Energy Activities at NASA Lewis Research Center: Robert Ragsdale, Solar Energy Branch, NASA Lewis Research Center
4:30-4:45	Summary of NASA Marshall Residential Solar Collector Experiments: Joseph Dabbs, NASA Marshall Space Flight Center
4:45-5:00	Status of the NASA-Lewis Flat-Plate Collector Tests with a Solar Simulator: Fred Simon, NASA-Lewis Research Center
5:00-5:15	Solar Collector Performance Evaluated Outdoors at NASA-Lewis Research Center: Richard Vernon, NASA-Lewis Research Center
5:15-5:30	Comparative Measurements of Absorptance and Emittance for Selective and Non-Selective Collector Coatings: Glen McDonald, NASA-Lewis Research Center
5:30-5:45	Questions and Discussion on Session 8
5:45-7:30	Dinner Break
7:30-10:30	Meetings of the Individual Working Groups

SATURDAY, NOVEMBER 23, 1975

Session 9 PANEL DISCUSSION BY COLLECTOR USERS

Chairman: Thomas Pretorius, Office of Intergovernmental Science and Utilization, NSF/RANN

Facilitator: John Duffie, Solar Energy Laboratory, University of Wisconsin

Opening Presentations

8:30-8:45 AM — Users' Experience with Solar Water Heater Collectors in South Florida: Jerome Scott, School of Business and Economics, University of Delaware

8:45-8:55 — An Architect's View: William Grover, Charles W. Moore Associates

8:55-9:05 — The Consulting Mechanical Engineer's Point of View: Peter Flack, Flack and Kurtz Consulting Engineers

9:05-9:15 — Solar Collectors and the Mobile Home: Kenneth T. Stringer, Jr., Mobile Home Manufacturers' Assoc.

9:15-9:40 — Questions and Discussion on Session 9.

Session 10 — WORKING GROUP REPORTS

Chairman: Robert Swartman, ASME Solar Energy Div.
Facilitator: Harold Hay, Skytherm Processes & Engr'g

9:40-9:50 — Flat Plate Liquid Heating Collectors: Harold Lorsch, National Center for Energy Management and Power, University of Pennsylvania

9:50-10:00 — Flat Plate Air Heating Collectors: Kudret Selcuk, Spacecraft Power Section, JPL

10:00-10:10 — Focusing Collectors: Erich Farber, Solar Energy Laboratory, University of Florida

10:10-10:25 — Coffee Break

10:25-10:35 — Materials & Components: John Duffie, Solar Energy Laboratory, University of Wisconsin

10:35-10:45 — Numerical Models: William Beckman, Solar Energy Laboratory, University of Wisconsin

10:45-10:55 — Testing and Standards: John Yellott, College of Architecture, Arizona State University

10:55-11:05 — Questions and Discussion on Session 10

Session 11 — SOLAR ENERGY PROGRAMS IN FEDERAL AGENCIES

Chairman: Harold Horowitz, Division of Advanced Energy Research and Technology, NSF/RANN
Facilitator: Redfield Allen, Dept. of Mechanical Engineering, University of Maryland

11:05-11:15 — General Services Administration: M. Ray Whitley, Public Building Services, GSA

11:15-11:25 — Federal Energy Administration: Robert Jones, Office of Energy Conservation and Environment, FEA

11:25-11:35 — National Science Foundation/Research Applied to National Needs, Office of Public Technology Projects: Alex Schwarzkopf, NSF/RANN, PTPO

11:35-11:45 — National Science Foundation/Research Applied to National Needs, Div. of Advanced Energy Research and Technology: Lloyd Herwig, NSF/RANN, AERT

11:45-12 Noon — Questions and Discussion on Session 11 and on Workshop in General

12:00 Noon — Adjournment

NSF/RANN WORKSHOP ON SOLAR COLLECTORS
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