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COMPARATIVE PERFORMANCE OF TWO TYPES OF EVACUATED TUBULAR SOLAR COLLECTORS IN A RESIDENTIAL HEATING AND COOLING SYSTEM

EXECUTIVE SUMMARY

FINAL REPORT FOR THE PERIOD
1 OCTOBER 1977 TO 30 SEPTEMBER 1978
(Including 1974-1977 operating results comparisons)

G.O.G. LÖF
W.S. DUFF

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SOLAR ENERGY APPLICATIONS LABORATORY
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

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EXECUTIVE SUMMARY

ABSTRACT

Two types of evacuated tubular solar collectors have been operated in space heating, cooling, and domestic hot water heating systems in Colorado State University Solar House I. An experimental collector from Corning Glass Works supplied heat to the system from January 1977 through February 1978, and an experimental collector from the Philips Research Laboratory, Aachen, which is currently in use, has been operating since August 1978. A flat absorber plate inside a single-walled glass tube is used in the Corning design, whereas heat is conducted through a single glass wall to an external heat exchanger plate in the Philips collector. The respective aperture areas are 50.0 m^2 and 44.7 m^2. Since system designs and conditions of operation were not identical, efficiencies and energy deliveries of the two evacuated tubular collectors should not be compared without recognition of these factors. But in comparison with conventional flat-plate collectors, both types show substantially reduced heat losses and improved efficiency.

In August and September 1977, 54% and 53% of the solar energy on the glass surface of the Corning collector was delivered to storage mainly for air conditioning use. In the same months of 1978, 29% and 31% of the solar energy on the glazed area of the Philips collector was delivered. Investigation showed that a photochromic property of the glass cover on the Philips collector had caused a degradation in solar transmission from 91% (new) to 82% (after ample solar exposure). If low-iron glass having permanent transmissivity of 91% had been used, computation shows system collection efficiencies of 36% rather than 29% in August and 38% rather than 31% in September 1978. Computed efficiencies and load shares based on 91% cover glass transmission are shown in parentheses.

Proportions of domestic hot water and cooling requirements carried by solar with the Corning collector and Arkla absorption chiller were 41% and 55% in August and September 1977, whereas 23% (30%) and 43% (50%) of the 1978 requirements (involving also a small heating load in September)

were met by solar energy delivered from the Philips collector. Heat delivery from both systems exceeded that from the previously used flat-plate collector, occupying approximately the same roof space, by factors of 2 to 4 at the 70°C to 90°C temperatures used for chiller operation.

For space heating and hot water supply in winter, average monthly heat delivery efficiency of the Corning collector ranged from 49% to 60% of the incident solar energy. The portion of the space heating and domestic hot water load carried by solar energy through fall and winter ranged from 50% to 74% with a four-month contribution of 61% of the total requirements. Heating season data on the Philips collector are currently being analyzed.

1.0 OBJECTIVES OF THE PROJECT

The primary objective of the project is the evaluation and improvement of systems for space heating, cooling, and hot water supply by use of solar energy collected in liquids circulated through flat-plate and evacuated tubular collectors. Specific objectives of the projects during the 1977-1978 year were:

(1) Evaluation of system performance for space heating and for space cooling with two types of evacuated tubular collectors

(2) Comparison of the evacuated tube collector systems with a flat-plate system

(3) Evaluation and improvement of absorption cooling systems supplied with solar heated water from evacuated tube collectors and

(4) Participation in the planning and evaluation of a solar heating project in the Federal Republic of Germany

2.0 SYSTEM DESIGN

During the period January 1977 to February 1978, a heating and cooling system in CSU Solar House I was supplied with solar heat from 50.0 m^2 (aperture area) of evacuated tubular liquid collectors (39.9 m^2 absorber area) fabricated by the Corning Glass Works. Since August 1978, the system has been supplied with solar heat from 44.7 m^2 (aperture area) of evacuated tubular collectors (40.6 m^2 absorber area) furnished by the Philips Research Laboratory, Aachen, FRG. Both collectors are experimental, the Corning design involving a flat-plate collector surface inside a single glass tube, with liquid circulation through copper tubing bonded to an internal absorber plate and sealed through the end of the glass tube. This collector represents the state-of-the-art in high efficiency collectors. In the Philips design, radiation is absorbed on the inside surface of the lower half of evacuated single glass tubes held (by springs) in contact with corrugated aluminum extruded plates through which the heat collection liquid is circulated. This design has the potential of being an integrated part of a roof where the tubes act as shingles. In the experimental system in Colorado, this collector has an additional glass cover which may not be necessary in a final version. Cross-sectional sketches of the two evacuated tubular collectors are shown in Figures ES-1 and ES-2.

The evacuated tubular collectors have been operated on a platform adjacent to the house with separate heat exchanger and storage tank so that the roof-mounted flat-plate collector, used since September 1974, could continue operation either as an energy supply to the house or in association with a heat rejection system designed for simultaneous operation with a simulated house load. Figure ES-3 shows the two solar heat collection and storage systems. Heat is supplied to storage by circulating a 50% ethylene glycol solution through a closed loop comprising the collectors, a tube-and-shell heat exchanger for transfer to storage, and (during part of the operating period) a small exchanger for preheating domestic hot water. For heat storage, water is circulated through the storage exchanger from an insulated tank of 4277 liter capacity, and potable water is pumped through the small exchanger from a 300 liter tank in which solar preheated water is stored prior to final heating in a 150 liter gas-fired water heater.

Also shown in Figure ES-3 is the heat rejection system associated with the collector/storage assembly not connected to the house load.

Figure ES-4 shows heat delivery to the rooms by circulating air through a duct-mounted finned-tube exchanger supplied with warm water from solar storage or from an auxiliary gas-fired hot water boiler. Cooling is provided from a 10.5 kW (3-ton) Arkla WF-36 water chiller supplied with solar heated water at 70°C to 90°C from storage or auxiliary. House air is cooled and dehumidified in a finned coil through which chilled water at 7°C is circulated. Heat is removed from the chiller by circulation of water through a cooling tower. During part of the operating period, domestic hot water could also be supplied from an exchanger in the storage-to-load loop.

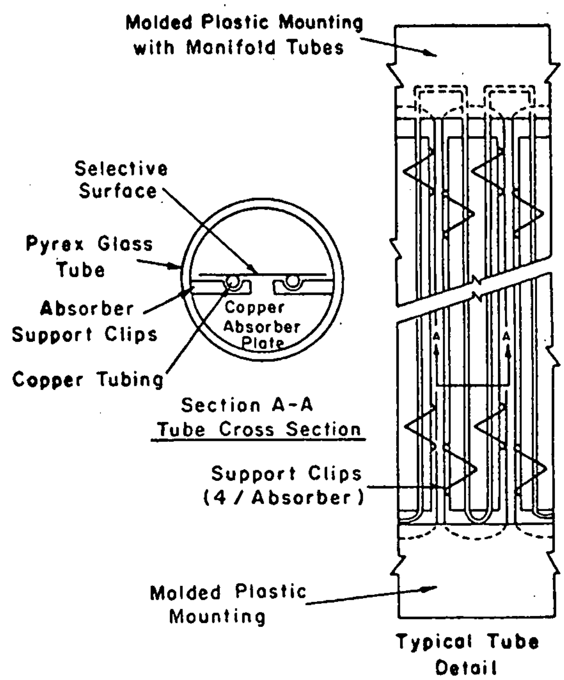

Figure ES-1. Evacuated Tubular Collector - Corning Design

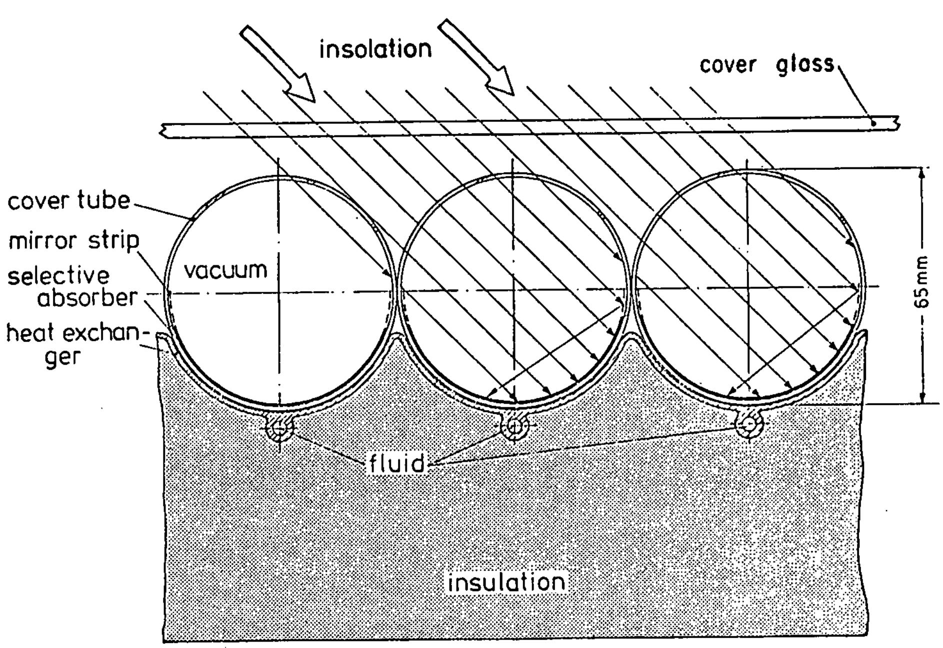

Figure ES-2. Evacuated Tubular Collector - Philips Design

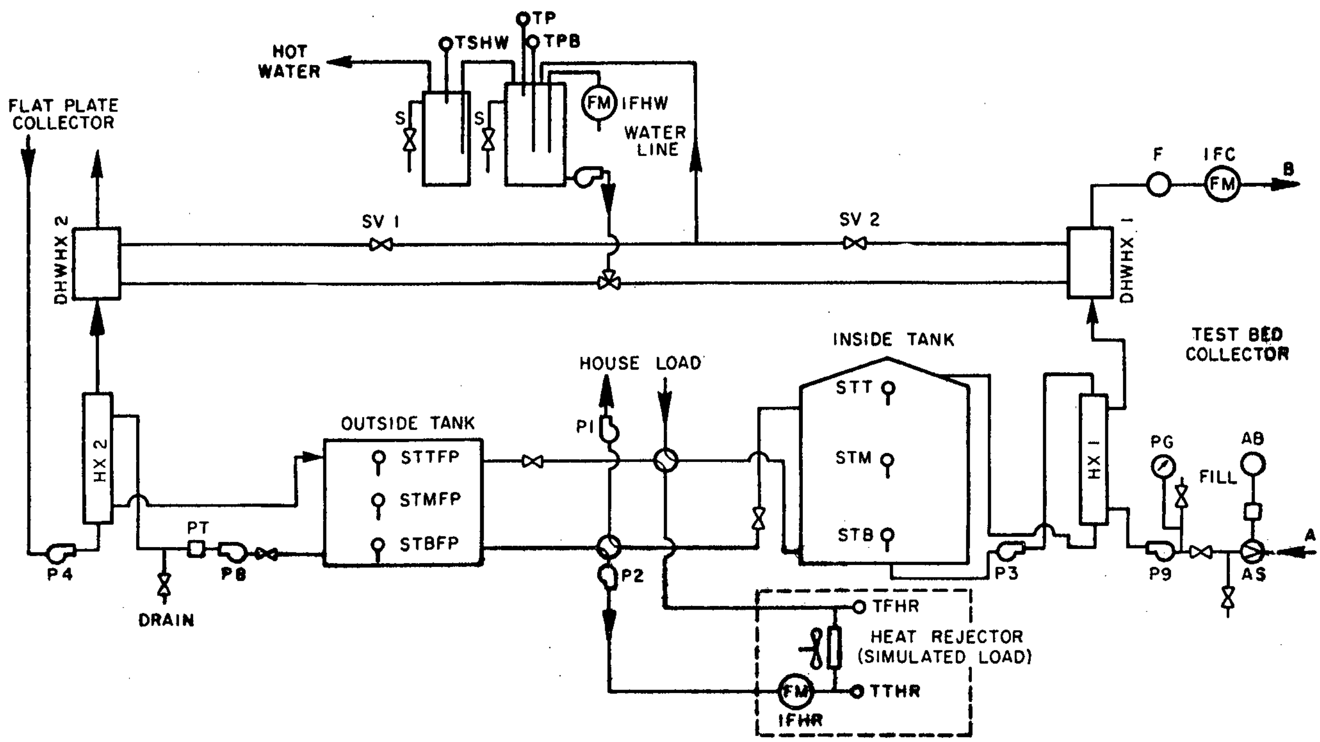

Figure ES-3. Solar Collection and Storage System, CSU Solar House I (Domestic hot water heater shown in location used prior to April 1978)

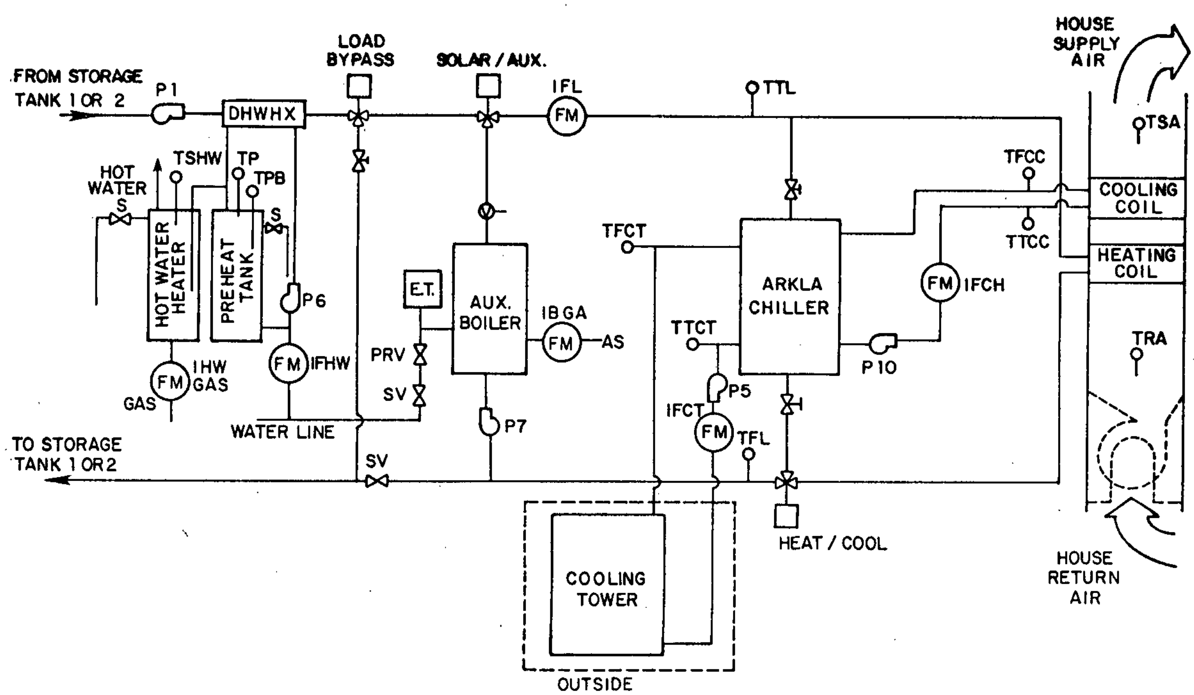

Figure ES-4. Solar Heating Utilization System - CSU Solar House I (Domestic hot water heater shown in location used after April 1978)

3.0 THERMAL PERFORMANCE

3.1 Heating and Cooling Seasons, 1974 to 1977

In the years preceding the period of this report, when the site-built flat-plate, double glazed, non-selective surface collector was used, 12% to 25% of the incident solar energy was collected for use in the supply of hot water, space heating, and space cooling. The contribution of solar to the total energy required for cooling ranged from about 20% to 50%. In 1974 through 1976, a direct expansion Model 501 Arkla absorption air conditioner was used.

The portion of the monthly space heating demand carried by solar ranged from a low of 36% when the flat-plate collector was used to a high of nearly 100% following the installation of the Corning evacuated tubular collectors. Representative solar contributions to the portion of the winter heating and hot water load carried by solar increased from 36% and 45% in January and February (1976) to 71% and 80%, respectively, in 1977. Domestic hot water preheating was provided by solar, usually to the extent of about half the total domestic hot water requirement. Prior to May 1976, domestic hot water was preheated in a heat exchanger supplied with water from the main solar heat storage tank. This heat exchanger was then moved to the collector loop, where it was used for water heating only when solar heating of main storage was impossible. This design was found to be less effective for hot water utilization of solar energy, so the exchanger was moved to the storage-to-load loop, as shown in Figure ES-4, in April 1978. Other system changes were made from time to time, as detailed in the body of this report.

3.2 Cooling Season 1977 and Cooling Season 1978

In 1977 and 1978, cooling was supplied by a Model WF-36 Arkla chiller. Daily average solar radiation and collection, by month, is shown in Figure ES-5. It is seen that in August and September 1977, 54% and 53% of the solar energy incident on the Corning collector was collected and delivered to storage while, in the same months of 1978, 29% (35¢ with 91% cover glass transmission) and 31% (38%) of the incident solar energy on the Philips collector was delivered to storage. Figures ES-6 and ES-7 show that the portions of domestic hot water and cooling requirements carried by solar with the Corning collector and Arkla absorption chiller were 41% and 55% in August and September 1977, whereas 23% (30%) and 43% (50%) of the 1978 requirements (involving a small heating load in September) were met by solar delivered from the Philips collector.

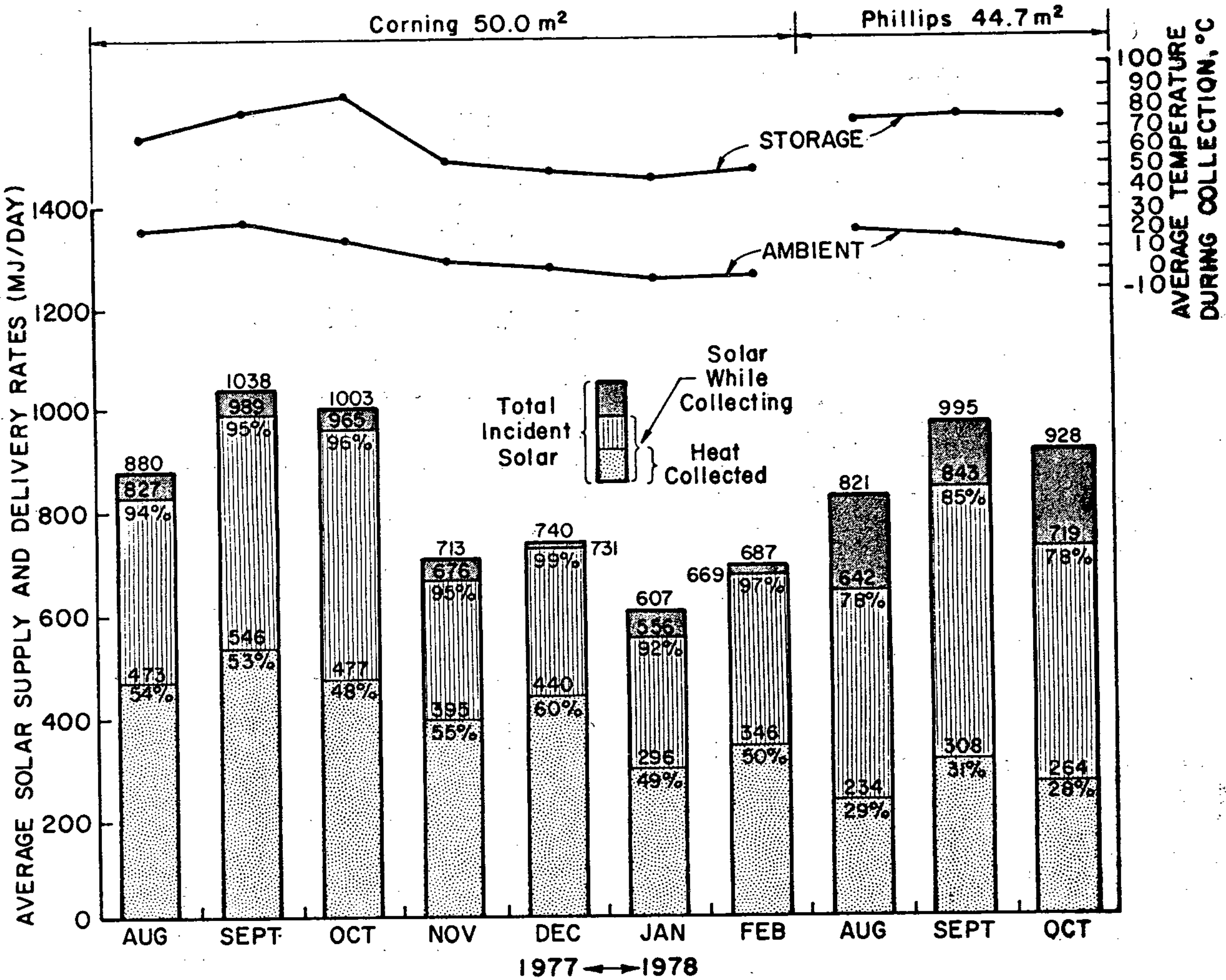

Fig. ES-5. Solar Radiation and Collection, August 1977 to October 1978, CSU Solar House I

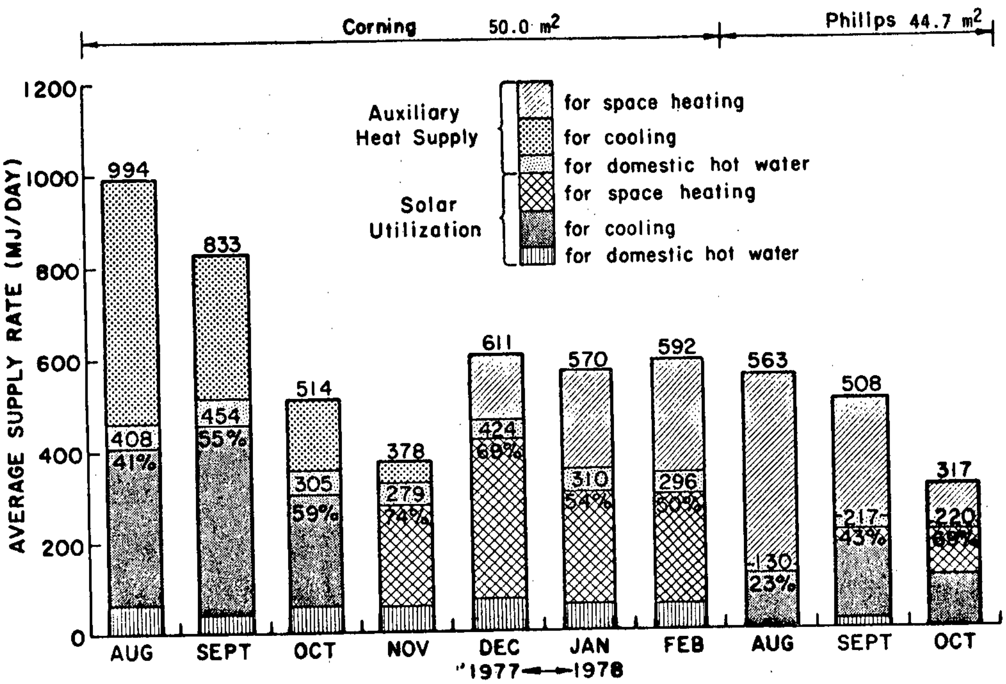

Figure ES-6. Solar and Auxiliary Use, August 1977 to October 1978, CSU Solar House I

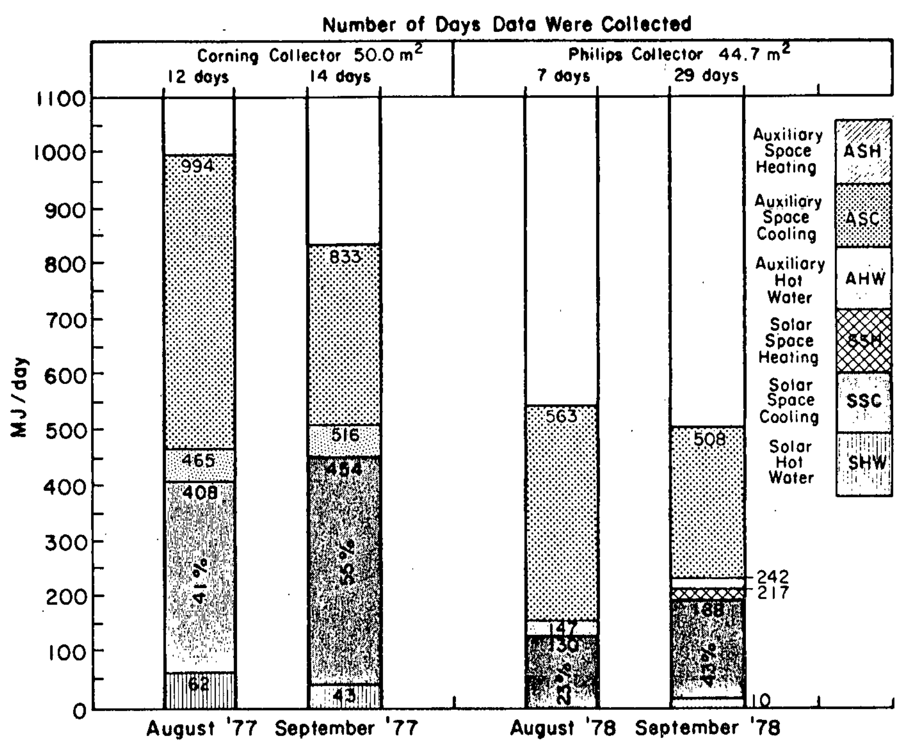

Figure ES-7. Solar and Auxiliary Energy Use During Cooling Season, 1977-1978, CSU Solar House I

Previous comparison of the output of the Corning collector and the site-built flat-plate collectors showed considerably higher solar heat deliveries and cooling supply with the evacuated tubular type.

3.3 Heating Season, 1977-1978

Monthly average daily collection of heat in two evacuated tubular systems and contributions to monthly heating requirements are shown in Figures ES-5 and ES-6. Heating was not required in the fall of 1978 until mid-October, so nearly all of the heating data in this report are based on operation with the Corning collector.

Solar energy system collection efficiency with the Corning collectors (Figure ES-5) ranged from 49% to 60%. These figures are based on radiation received during the day on the total aperture area of the collector panels, not including the space between the collector modules for piping and heaters. As a percentage of solar energy received during collector operation (pump running), the efficiencies based on the same collector panel area ranged from 50% to 61%, there being little difference between total incident solar and solar while collection took place.

Figure ES-6 shows that the portion of the space heating and domestic hot water load carried by solar energy through fall and winter of 1977-1978 ranged from 50% to 74%, a four-month contribution of 61%.

These results may be compared with the performance of the same system during the 1976-1977 heating season, in which 47% (January) to 62% (April) of the incident solar radiation was collected. Contributions to space heating and hot water requirements were 69% to 84%, a four-month average of 76%. Although the percentage of total load carried by the Corning collector was less in 1977-1978 than in the 1976-1977 heating season, the total heat requirements were considerably higher (four winter months compared with two winter and two spring months) while the amounts of solar heat delivered were nearly the same.

4.0 ELECTRIC POWER USAGE

Three centrifugal pumps are used for liquid circulating in the heating system in Solar House I, one small pump for domestic hot water supply, and one centrifugal blower for air circulation and distribution. The total nameplate rating of the electric motors is 1.11 kW in the system employing the Philips collector. Two additional pumps and a fan (for the cooling tower) required an additional 0.77 kW for chiller operation.

In this experimental installation, economical utilization of electricity for system operation was not a project objective. Oversize pumps, numerous measuring devices, and other energy consuming equipment were employed. High electricity usage for solar energy collection and distribution was therefore recorded. Typical electrical requirements for operation of the heating system (natural gas auxiliary) were 34% of the solar heat supplied, equivalent to a coefficient of performance of 2.94. For cooling, additional electrical consumption reduced the COP (solar heat delivery to cooling machine and to hot water heater divided by system electrical consumption) to 1.76. By selection of more efficient motors and pumps, and by minimizing pressure losses in the system, it is believed that electricity consumption can be reduced to approximately 12% of the total solar energy delivery.

5.0 MECHANICAL PERFORMANCE AND OPERATING RESULTS

There were no major breakdown in the solar heating or cooling systems during the year. Both of the evacuated tubular collectors operated without difficulty or irregularity. Prior to August 1977, the control sensor on an outlet tube in the Corning collector failed to provide reliable temperature indications inside the collector, which resulted in occasional boiling in the collector tubing. Placement of a small sensor directly inside the fluid outlet tube, but within the evacuated tube zone, solved the problem.

In their present form, neither of the evacuated collectors appears ideally suited for use in locations where snowstorms are common. Accumulation of snow reduces performance; in cold weather, even though sunny, the collector may remain snow-covered for several days. Methods for snow removal are being investigated.

Failure of automatic valves to completely close led to occasional system malfunctions, with resulting efficiency losses. Excessive heat losses from storage continued to reduce system effectiveness for cooling, by adding undesirable heat to the building and reducing the time the system could operate on solar. Service was required on two occasions to correct loss of vacuum in the absorption chiller.

Numerous malfunctions and outages occurred in the monitoring system and data acquisition equipment. Approximately one-third of the data were lost or unusable, even with daily maintenance of the monitoring system. The need for continuous servicing of data acquisition equipment or for more reliable equipment was thoroughly demonstrated.

6.0 SYSTEM COMPARISONS

During the present 12-month period of this investigation, two types of comparisons were made. These were system performance comparisons with Corning evacuated tubular collectors and with Philips evacuated tubular collectors, and system performance comparisons with domestic hot water heat exchange in the collector loop and in the storage-to-loads loop. Early comparisons, involving the use of flat-plate collectors, chilled water storage, direct expansion absorption air conditioner, and domestic hot water heat exchange from storage, have been previously reported. The results show that:

(1) The system with evacuated tubular collectors provided more than twice as much energy for space heating and three times as much energy for cooling as an equal net area of flat-plate collector.

(2) Storage of chilled water offers no advantage for solar cooling.

(3) Solar cooling capability of the absorption chiller (for water) is substantially greater than the solar cooling provided by the direct expansion type (for air).

(4) Use of the domestic hot water heat exchanger in the collector loop and the control strategy employed provided an increase in solar energy delivered for cooling, but the decrease in energy supplied to hot water was even greater; the heat exchanger was therefore moved to the load loop side of the storage tank.

An unexpected finding in the analysis of performance of the experimental Philips collector was the low solar transmissivity of the flat glass covers as a result of their apparent solarization or darkening under exposure to the high levels of ultraviolet radiation in Colorado. The plate glass cover used was a commercially available glass indicated by the manufacturer as a high transmission glass. Discovery of a discrepancy between the efficiency of the first collector module tested at the Philips Labs in Aachen, West Germany and the measured efficiency in the later collector modules installed at Solar House I, resulted in the investigation which disclosed the solarization effect. Cover glass transmission was found to have decreased from about 91% before exposure to 81-83% after exposure. The cover glass will be replaced with a low-iron type and the performance differences will be measured.

In order that the performance of the two evacuated tubular collectors can be more directly compared, the heat delivery which should be obtained from the Philips collectors with a low-iron cover glass was computed by use of the measured solar and temperature data. Conclusions on the relative effectiveness of the two evacuated tube collector designs are not yet possible for several reasons:

(1) Use of an atypical glazing for the Philips collector has already been explained.

(2) A difference in the utilization of the solar system for hot water supplies in the two years reduced comparability of results.

(3) For several weeks in the summer of 1978, an imperfectly closed valve permitted hot water from solar storage to leak through the air heating coil, simultaneously with solar heat supply to the chiller. The resulting reheating of the cooled air reduced air conditioning output and increased auxiliary fuel use.

(4) The control strategy, one of the numerous operating procedures evaluated in the course of the research, adversely affected the 1978 energy collection. In order to obtain the maximum cooling capacity shown in Figure ES-8 upon initial operation with solar, the initiating temperature for supplying solar heated hot water to the chiller had been set at 80°. The high temperature requirement for collector operation (about 85° to supply the heat exchanger) resulted in a greater efficiency penalty against the Philips design, so further evaluation is expected to be made by supplying the chiller with solar heat at temperatures as low as 70°C.

Further investigation of these factors and their effect on system performance is in progress.

7.0 CONCLUSIONS

The results of the present investigation show the excellent performance of the evacuated tubular collectors, both with respect to ease of operation and also with respect to efficiency of solar collection. Figure ES-9 shows that net heat delivery per unit area of effective collector surface is double to triple that of the flat-plate collector previously used. Solar cooling is considerably more effective, but the overall capability of solar

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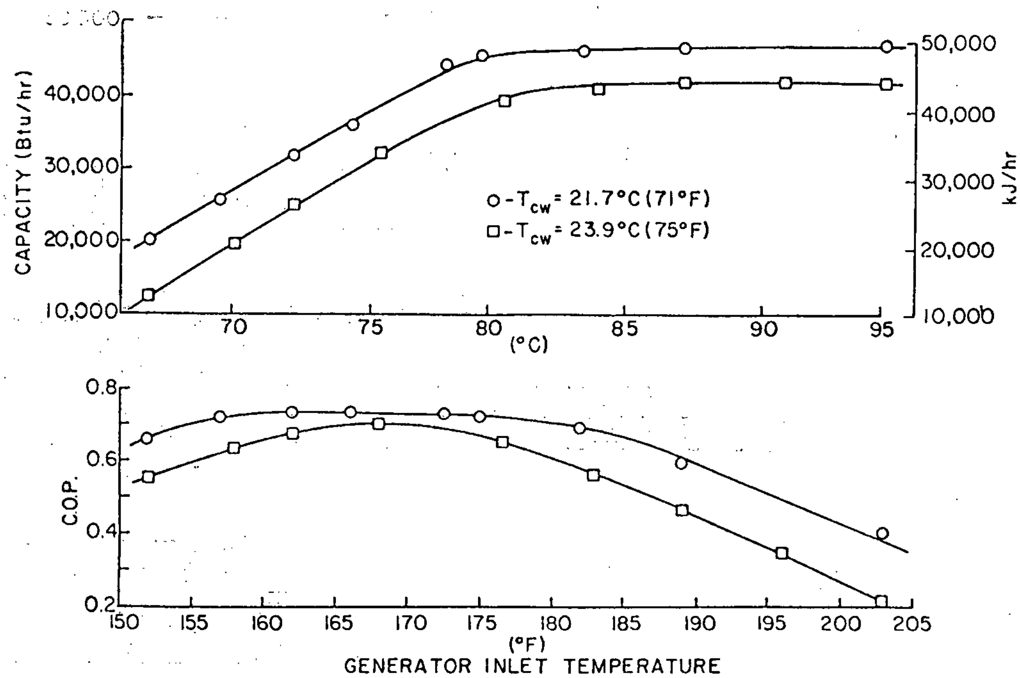
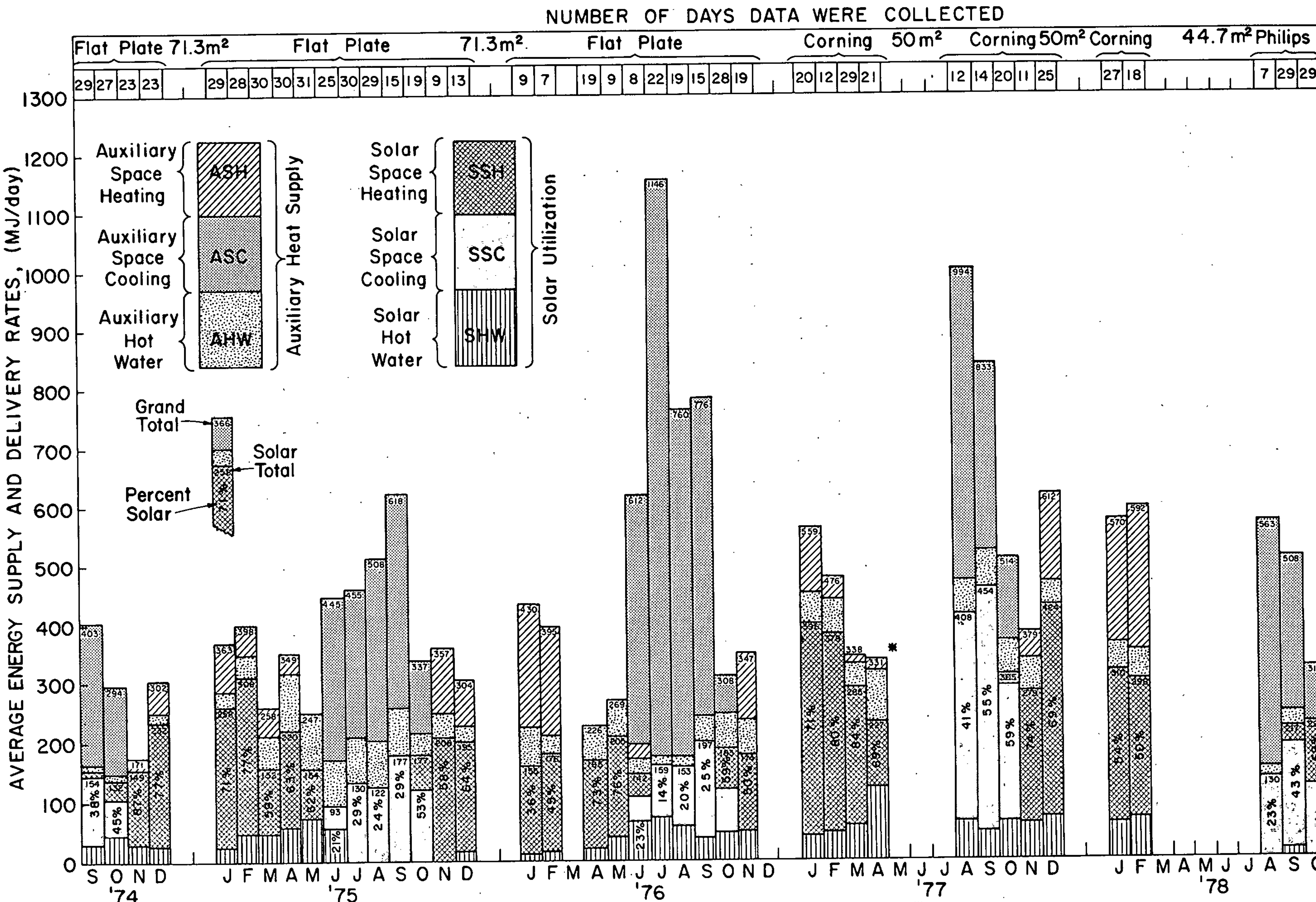


Figure ES-8. Performance Characteristics of the Arkla WF-36 Absorption Chiller, 50% Solution Concentration

energy to meet substantial cooling requirements effectively and economically is limited by factors such as the substantial heat losses from the system (particularly the hot storage tank), transient operation of the chiller, and other inefficiencies.

The discrepancy between the CSU observed performance and the collector efficiencies independently measured in Germany is due mainly to the change in solar transmissivity of the cover glass with exposure to ultraviolet radiation. Differences in several operational factors in the two years of system evaluation, and the limited number of corresponding months of data, necessarily limit comparability of the results. Further experimental work and data analysis are in progress.

The Solarhaus Freiburg, West Germany cooperative project began operations with the same Corning and Philips collectors near the end of this reporting period. Data and experience exchange is in progress.



Performance of Flat-Plate, Corning Evacuated and Philips Evacuated Tubular Collectors, 1974-1978.

* Temporarily Reduced Collector Area of $35 m^2$ for Month

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