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COMPARATIVE PERFORMANCE OF TWO TYPES OF EVACUATED TUBE SOLAR COLLECTORS IN A RESIDENTIAL HEATING AND COOLING SYSTEM - THE PROGRESS REPORT

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ABSTRACT

Two types of evacuated tube 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 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. In comparison with conventional flat-plate collectors, both types show 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. The respective figures for the same months of 1978 have been reduced by the degradation of the transmission of the glass cover on the Philips collector from 91% to 82%. The efficiency figures in brackets below correspond to the performance that would be obtained with low-iron glass (i.e., 91% transmission). In the same months of 1978, 29% (36%) and 31% (38%) of the incident solar energy on the glazed area of the Philips collector was delivered to storage. 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. The respective glazed areas are 50.0 square meters and 44.7 square meters. 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 75°C to 90°C temperatures required for chiller operation.

For space heating and hot water supply in winter, the solar 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. Data on the Philips collector are currently being analyzed.

1. 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 (glazed 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 (glazed area) of evacuated tubular collectors (40.6 m^2 absorber area) furnished by the Philips Research Laboratory, Aachen. 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 is not necessary in the final version. Cross-sectional sketches of the two evacuated tube collectors are shown in Figures 1 and 2.

The evacuated tube 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 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 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 a 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 3 is the heat rejection system associated with the collector/storage assembly not connected to the house loads.

Figure 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

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90°C from storage or auxiliary. House air is cooled and dehumidified in a finned coil through which chilled water at 7° is circulated. Heat is removed from the chiller by circulation of water through a cooling tower.

2. THERMAL PERFORMANCE, 1977-1978

Cooling Season 1977 and Cooling Season 1978

Daily average solar radiation and collection, by month, is shown in Figure 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% (36%) and 31% (38%) of the incident solar energy on the Philips collector was delivered to storage. Figures 6 and 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.

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 tube types.

Heating Season, 1977-1978

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

Solar collection efficiency with the Corning collectors (Figure 5) ranged from 48% to 60%. These figures are based on radiation received during the day on the total glazed area of the collector panels, not including the space between the collector modules for piping and headers. 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 6 shows that 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%.

3. COMPARABILITY OF RESULTS

An unexpected finding of the analysis of performance of the experimental Philips collector was the low solar transmissivity of the flat glass covers and their apparent solarization or darkening under solar exposure. 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 a new collector, measured in a solar simulator before installation in CSU Solar House I, and the measured efficiency in routine operation after installation, resulted in the investigation which disclosed the phototropic effect. Cover glass transmission was found to have decreased from about 90% before exposure to sunlight having a high ultraviolet component to 81-84% after exposure. The cause of the transmissivity change is currently under investigation and the cover glass will be replaced with a low-iron type.

In order that the performance of the two evacuated tube 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 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. The minimum temperature of hot water supplied to the chiller had been set at 85° in order to obtain the maximum cooling capacity shown in Figure 8. The high temperature requirement for collector operation (about 90° 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.

4. ELECTRIC POWER USAGE

Three centrifugal pumps are used for liquid circulation 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. MECHANICAL PERFORMANCE OPERATION RESULTS

There were no major breakdowns in the solar heating or cooling systems during the year. Both of the evacuated tube 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.

Neither of the evacuated collectors appears ideally suited to use 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. 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 35% of the data were lost or unusable, even with daily maintenance of the monitoring system. The need for continuous servicing of data acquisition equipment was thoroughly demonstrated.

6. CONCLUSIONS

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

ACKNOWLEDGEMENT

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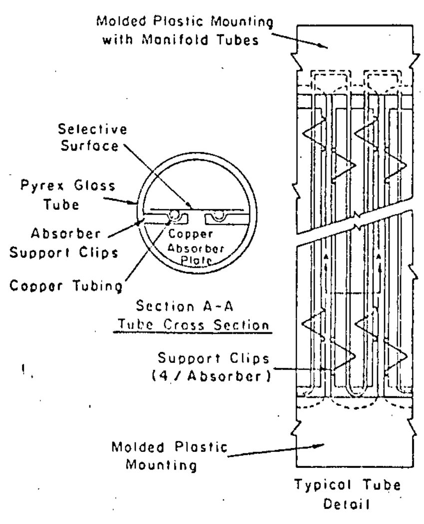

Fig. 1. Evacuated Tube Collector - Corning Design

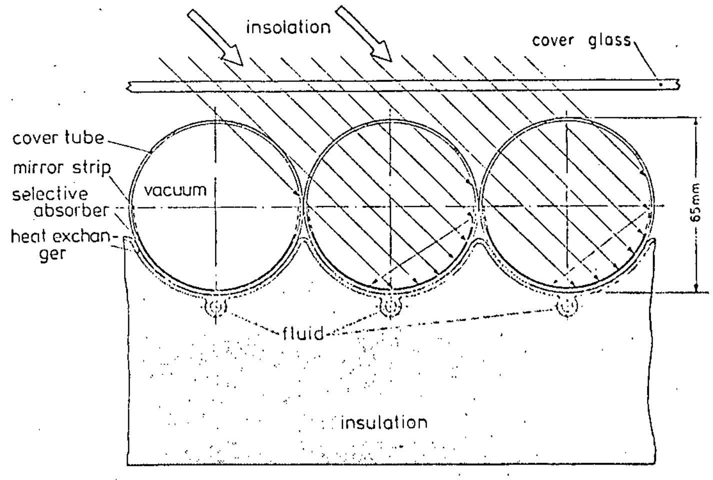

Fig. 2. Evacuated Tube Collectors - Philips Design

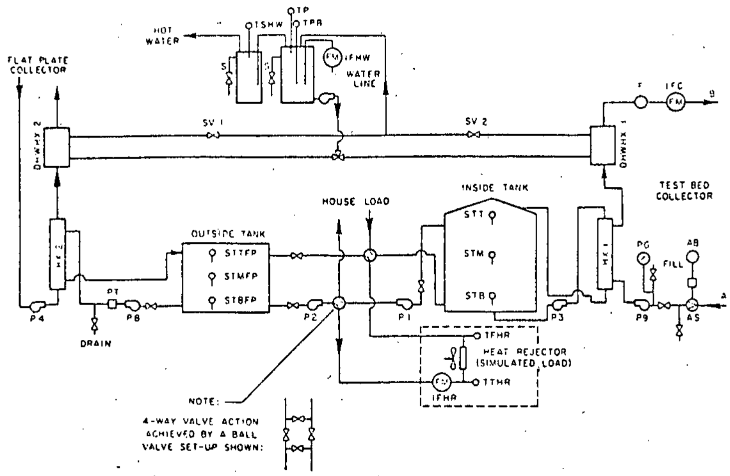

Fig. 3. Solar Heat Collection and Storage System, CSU Solar House I

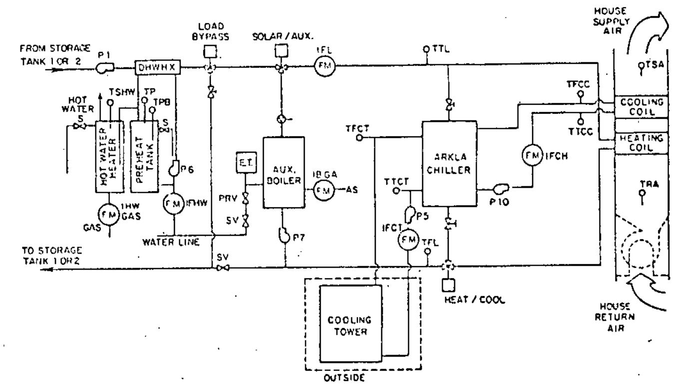

Fig. 4. Solar Heat Utilization System - CSU Solar House I

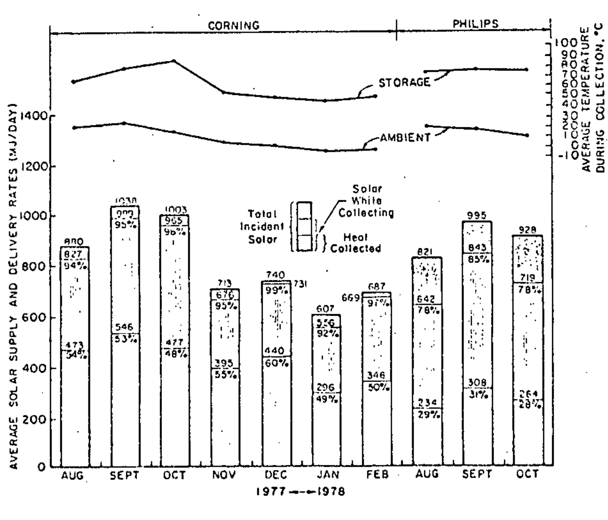

Fig. 5. Solar Radiation and Collection, August 1977-October 1978, CSU Solar House I

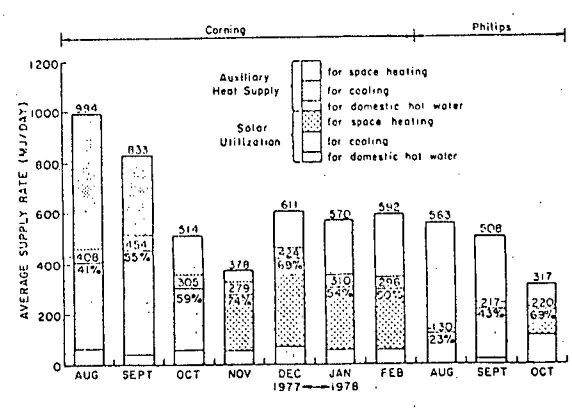

Fig. 6. Solar and Auxiliary Energy Use, August 1977-October 1978, CSU Solar House I

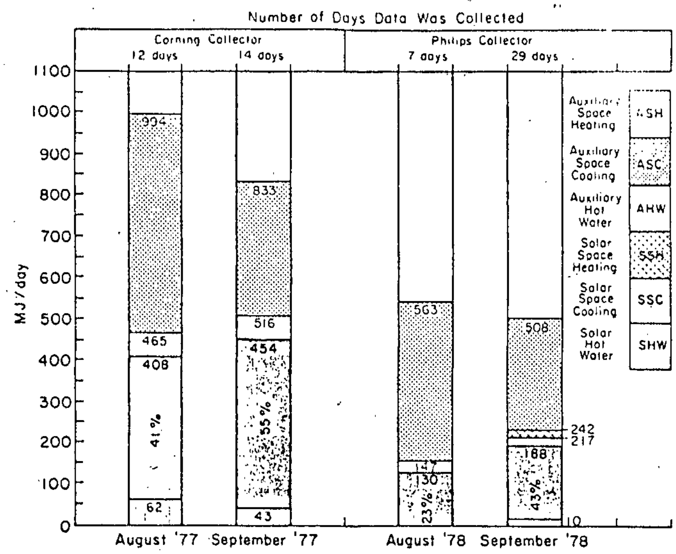

Fig. 7. Solar and Auxiliary Energy Use During Cooling Seasons, 1977-1978, CSU Solar House I

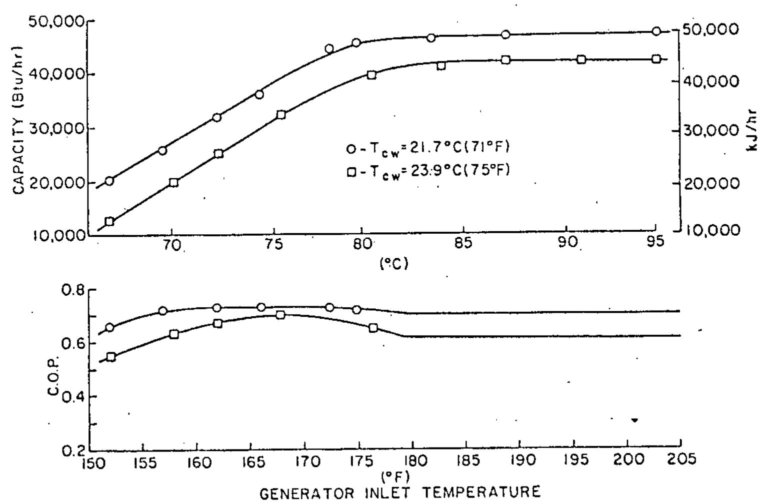

Fig. 8. Performance Characteristics of the Arkla WF-36 Absorption Chiller, 50% Solution Concentration

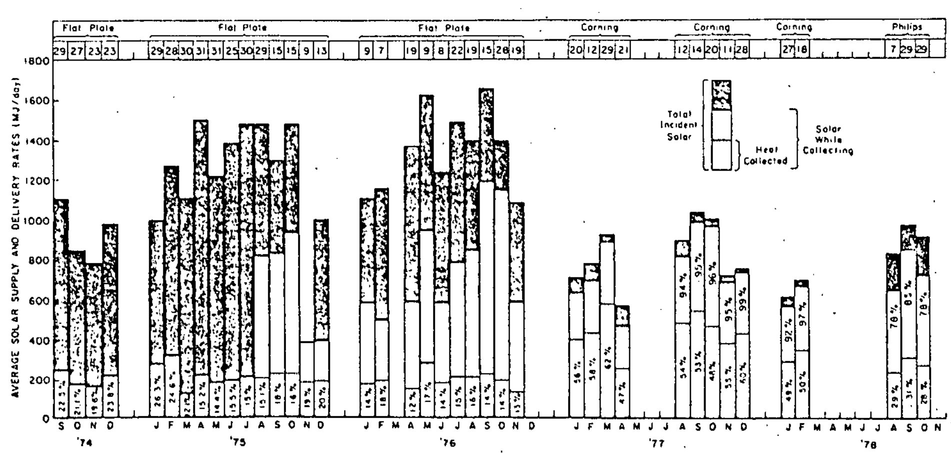

Fig. 9. Solar Radiation and Collection, Sept. 1974-October 1978, CSU Solar House I