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COMPARATIVE PERFORMANCE OF SOLAR HEATING
WITH AIR AND LIQUID SYSTEMS

Interim Progress Report, February 1, 1976—August 30, 1976

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MASTER

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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INTERIM PROGRESS REPORT
FOR THE PERIOD
1 FEBRUARY 1976 TO 30 AUGUST 1976

S. KARAKI
G. O. G. LOF
C. C. SMITH

AUGUST, 1976

PREPARED FOR
THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D. C.
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COMPARATIVE PERFORMANCE OF SOLAR HEATING WITH AIR AND LIQUID SYSTEMS

ABSTRACT

A performance comparison between an air solar system and a liquid solar system for space heating under nearly equal conditions has been obtained. The Colorado State University Solar House I is a liquid solar system which has been in operation since August 1974. Solar House II, which stands adjacent to and has a comparable heating load to Solar House I, is equipped with an air solar system. Solar House I has been continuously monitored since August 1974 and Solar House II has been monitored since February 1976.

Performance of the solar systems is reported in terms of the collector efficiency, the amount of space heating and service water heating load provided by solar energy, and the use of electrical energy to operate the solar equipment.

General characteristics of the two types of systems are also compared. Information concerning installation, operation, and maintenance of the systems have been documented and are discussed.

INTRODUCTION

In August 1974, the first solar heated and cooled house in the United States began operation at Colorado State University. Since that time, the solar system in this building has provided approximately three-fourths of the energy required for space heating, space cooling, and service water heating from solar energy. The energy is collected in an aqueous anti-freeze solution, stored in water, and used to provide heated or cooled air to the building.

In 1975, a second solar heated house was constructed at Colorado State University. It provides space heating and service hot water from solar air collectors. Solar heat is stored in a pebble-bed for heating during sunless periods. Cooling is provided by an evaporative cooler which is used during the night to cool the pebble-bed storage unit. During the day, warm room air is circulated through the pebble-bed and the cool return air is circulated through the building.

While the performance study of each system is a valuable contribution itself, the opportunity to compare air and water solar systems under nearly identical conditions is unique. The structures of Solar House I and Solar House II are identical except for interior partitions. The size, insulation, exposure, and use of the buildings are comparable. The heat load in Solar House II is somewhat greater than experience in Solar House I because of greater infiltration load. The buildings are only 50 meters apart, as shown in Figure 1, so all climatic factors are equal. The collectors on Solar House I and Solar House II are double-glazed flat-plate collectors with non-selective absorber surface. The absorber surface area on Solar House I is 69.7 square meters, and on Solar House II is 67.1 square meters.

DESCRIPTION OF LIQUID AND AIR SOLAR SYSTEMS

Liquid System - CSU Solar House I

The solar heating and cooling system in CSU Solar House I has operated since August 1974, without significant interruption. Design and performance information has been documented and reported, [1,2,3]. An aqueous antifreeze solution is heated in the site-built collectors, comprised of aluminum absorber plates with expanded tubes, a non-selective

Solar House I
(Liquid System)

Solar House II
(Air System)

Figure 1. Colorado State University Solar Houses

black coating, two layers of glass, and fiberglass insulation. Fluid is pumped through the collectors at the rate of 0.87 liters per minute per square meter of collector area.

As shown in Figure 2, heat is transferred in a tube-in-shell heat exchanger from the collector fluid to water circulated from and to a 4165-liter storage tank. Hot water from storage is pumped to an air duct heating coil for space heating, or to the generator of a lithium-bromide absorption air conditioner for space cooling, and to a heat exchanger loop for domestic hot water supply. A gas-fired boiler provides auxiliary space heating and an automatic gas water heater supplements the solar hot water supply. Warm or cool air is distributed to the rooms of the building in conventional manner.

Air System - CSU Solar House II

Air is used in Solar House II as the heat collection and heat transport fluid. The collector is similar to the liquid heating collector, with an absorbing surface covered by two glass panes and insulated beneath with fiberglass. The absorber is an air duct about one centimeter deep, 60 centimeters wide, and 5 meters long. Air at 10 liters per second per square meter of collector area is forced through the collectors. The air flows in parallel through 23 collector units at a velocity of 5 meters per second in the absorber passages.

Hot air from the collector (Figure 3) passes through a pebble-bed heat storage unit, or directly to the heated space when required. At night or during cloudy weather, air from the building space is heated by circulating it through the pebble-bed. Air from the collector and from the house is circulated through the pebble-bed in opposite directions to

Figure 2. Liquid Solar System Illustration (Solar House I)

LEGEND

EVC = EVAPORATIVE COOLER
 AUX = AUXILIARY HEATER
 HUM = HUMIDIFIER
 B1, B2 = BLOWERS
 P = RECIRCULATING PUMP
 MD = MOTORIZED DAMPER
 W/S = MANUAL WINTER/SUMMER
 DAMPER

Figure 3. Air Solar System Illustration
(Solar House II)

take advantage of the temperature stratification in the pebble-bed. The pebble-bed consists of 16,500 kilograms of rock of 2 to 4 centimeters in diameter. Domestic hot water in Solar House II is solar-heated in a duct coil located in the hot air stream from the collectors. Auxiliary heat is supplied by a gas duct furnace in the air circuit to the rooms.

Space Cooling in Solar House II

Cooling in Solar House II is not a solar energy system as it is in Solar House I. Advantage is taken of the low wet-bulb temperature prevalent in the local dry climate and the thermal capacity of the pebble-bed. At night, outdoor air is evaporatively cooled in an air washer and circulated through the pebble-bed to remove heat. The air is discharged from the pebble-bed to the exterior of the building. When cooling is needed during the day, house air is passed through the cool pebble-bed and delivered to the rooms.

A comparison of space cooling in the two houses is not reported in this paper because the system in Solar House II was first operated in the summer of 1976 and will be the subject of future reports.

Comparison of Air and Liquid Solar System Performance

Data used in the comparison of heating system performance in the two buildings were compiled from 14 January through 15 May. Both solar systems operated with only minor interruptions during this period, but some data are missing because of instrumentation failures. The periods of data loss are not believed to influence the results of the comparison. Solar preheating of domestic hot water and space heating are included in the comparison.

During the period from 14 January to 2 May, the liquid system in Solar House I provided 25,720 MJ of solar energy for space and service hot water which was 73.0 percent of the total load. During the same period the solar air heating system provided 40,020 MJ for space and service hot water heating in Solar House II, which was 72.7 percent of the total load.

Figures 4 and 5 represent, in bar chart form, the average daily total solar radiation on the collector surface, the total radiation on the collector surface when the collector was in operation, and the solar energy collected for space and service hot water heating.

It will be noted in comparing Figures 4 and 5, that the air system operated for a longer period of time during the day than the liquid system. This is a consequence of stratified heat storage in the pebble bed for the air system and nearly uniform temperature in the water storage tank of the liquid system. The propagation of the temperature profile through the pebble-bed during a typical charge-discharge cycle is shown in Figure 6. Because of the stratification, the temperature of the air returning to the collector from the bottom of storage is always near room temperature. Thus, the air collector can deliver useful heat from early morning to late afternoon: the liquid system starts up later in the morning and shuts off earlier in the afternoon because the water storage temperature is 12 to 15 °C greater than room temperature in the morning and as much as 25 to 35 °C greater by mid-afternoon. Over the period during which data were taken, the air system operated 45 percent longer during the day than the liquid system and collected 38 percent more heat. The collector efficiencies for the air collectors based on hourly data are shown on Figure 7.

Figure 4. Collector Performance, Liquid System
CSU Solar House I

Figure 5. Collector Performance Air System
CSU Solar House II

Figure 6. Propagation of Pebble-Bed Temperature Profile
(During Heat Storage Charge-Discharge Cycle)
February 7-8, 1976

Figure 7. Average Collector Efficiency During Full Hours of Bright Sunshine, Solar House II, February 1976

The monthly distributions of solar and auxiliary energy to the total space and water heating load are shown on Figures 8 and 9 for Solar House I and II respectively. The average solar contribution to total load for both systems was 73 percent during the period of measurement.

Electrical energy consumption by the solar equipment in the two systems was also compared. Electrical energy use is presented as the useful solar heat delivered for space heating divided by total electricity consumption. This electrical "coefficient of performance" for solar space heating was 11 for Solar House I and 15 for Solar House II.

CONCLUSIONS

The air system of Solar House II operated during a longer period of the day than the liquid system of Solar House I largely because of the temperature stratification in the pebble-bed storage. As a result, more solar energy was collected with the air system than the liquid system during the period of measurement. However, because of air leaks into the collector system, the additional energy collected in Solar House II was distributed into the building in an uncontrolled manner and lost from the building as an infiltration load. The solar systems in both houses provided 73 percent of the water and space heating loads during the period of measurement. When the air leakage into the collector system is reduced, the solar energy contribution to the total heating load will increase.

Figure 8. Distribution of Solar and Auxiliary to Total Load. CSU Solar House I

Figure 9. Distribution of Solar and Auxiliary to Total Load. CSU Solar House II

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