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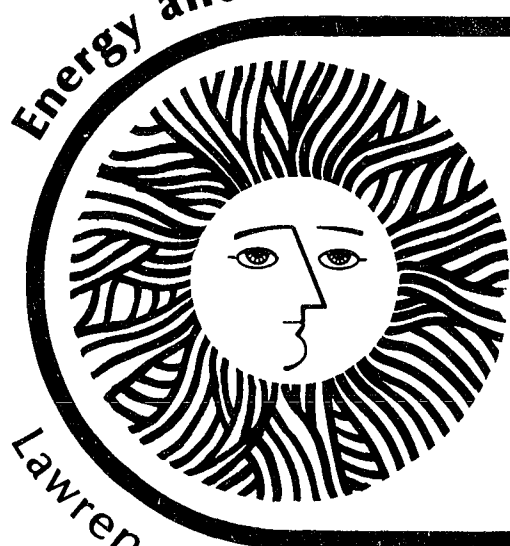
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**Experimental Test Facility For
Evaluation Of Solar Control Strategies**

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EXPERIMENTAL TEST FACILITY FOR EVALUATION OF SOLAR CONTROL STRATEGIES*

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INTRODUCTION

An experimental solar heating and cooling system has been constructed at LBL. It was designed to serve as a test system to check out the operation of an LBL-developed solar controller that looked promising in terms of its commercialization potential. However, it soon became apparent that the value of this controller could only be determined by conducting experimental measurements of its cost-effectiveness (i.e., its cost compared to its capability for reducing use of auxiliary energy); simple operational check out was not sufficient to justify commercialization of this type of controller. Accordingly, improvements were made in the experimental heating and cooling system to enable quantitative determination of the auxiliary energy savings made possible by using this type of controller. These improvements consisted of installation and calibration of accurate instrumentation, data acquisition capabilities, and development of simulated input and output devices that would allow repeated experiments using the same running conditions. In addition, the possibilities of further development of the heating and cooling system into an experimental test facility for a wide range of solar control strategies have been investigated.

SYSTEM DESCRIPTION

The solar heating and cooling system shown in Figure 1 is residential-sized, and includes the usual components: collectors, storage, loads, and associated plumbing. Water is used as the circulation fluid in both the collector and load loops; appropriate corrosion inhibitors have been added. The flow configuration is fairly generalized, to allow options such as direct collector-to-load operation (by-passing the storage tank), and independent operation of the collector and load loops. A simplified flow schematic as shown in Figure 2 is useful in analyzing the control options for operation of the heating and cooling system.

Appropriate sensors (temperature and flow) and actuators (solenoid valves, pumps, and auxiliary heaters) are dispersed throughout the system. At present, only on/off flow states are possible. Current plans call for modifications of pumps and/or valves such that the wider range of control strategies that require variable flow rates may also be tested.

A domestic hot water system is also included. It interacts with the solar system via a heat exchanger

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submersed in the hot water storage tank as shown in figure 3.

CONTROLLER DESCRIPTION

The system is now being controlled by a flexible, multi-input multi-output controller. It was designed to be intermediate in performance between a simple differential thermostat and an on-line microprocessor. A schematic of the solar controller is shown in Figure 4. Electrical signals from up to eight solid state temperature sensors are standardized. By use of a pin matrix board PPM pairs of the temperature sensors can be selected for comparisons. The logic signal outputs from the comparators are used to drive the PROM chips, which contain control algorithms. The ON/OFF output commands ensue from the PROMs. Algorithm changes are implemented by replacement of or by programming the PROM.

The prototype version of this controller was fabricated so that it could be readily tested. Thus many features (such as manual override, display, accessibility to internal signals and calibrations) were incorporated that allowed experimental flexibility, but which need not be included in a commercial version. Although not originally designed for this purpose, this flexibility now allows us to bypass the PROMs with an external interface to a microcomputer, considerably broadening the testing capabilities of our experimental system without having to change the controller hardware. This microcomputer has been acquired for other purposes, as described below, but is essentially fully available for solar control functions as well.

CONTROL ALGORITHMS

The state of the solar system is defined, at any given time, by the values of those sensors that are used as inputs to the solar controller. The present set includes five temperature sensors, one flow switch, and a multi-stage room thermostat. The analog signals from the temperature sensors are compared in pairs, with appropriate offset and hysteresis values, generating binary signals as in conventional differential thermostats. These resultant binary signals, plus those from the flow switch and the thermostat, are processed to provide the PROM inputs. The control algorithm in the form of a truth table is used to code the PROM chip, which is the device that performs the input-to-output mapping. The resulting output signals from the PROM are used to enable the valves, pumps, and auxiliary heaters.

The first series of experimental test runs will involve ON/OFF control modes. The large, but finite, number of possible algorithms is readily reduced to a

manageable set by the application of some reasonable guidelines. Examples of such guidelines are: use the collectors to drive the load directly whenever possible; when the load output fluid is hotter than the storage tank, return it to the storage tank--when it is colder than the storage tank, return it to the collectors; avoid heating the storage tank by the auxiliary heater; and so on.

Several approximations were made to reduce a manageable size the task of selecting a small set of algorithms for experimental test runs. The major approximations were the assumptions that the collectors and the storage tank could each be represented by a single state variable (one temperature sensor in each). Therefore, the controller algorithms aim to operate the system in a near-optimum fashion, and experimental verification will be necessary to select the best algorithm for any given set of operating conditions.

HEAT INPUT AND LOAD OUTPUT SIMULATORS

To make meaningful comparisons between alternative control algorithms, the heat input and load conditions must be reproducible. What differences in conditions do occur must be minor enough not to affect significantly the controller evaluation. Therefore, it was decided that the solar energy input to the system and the building load output should be supplied by simulation devices that would permit repeated runs under the same external conditions. Preferably these simulators would be driven by the same standardized weather tapes that are now available for computer simulation analyses.

HEAT INPUT SIMULATION--THE PSEUDO COLLECTOR

The heat input simulator, the pseudo collector shown in Figure 5, is principally a boiler plus its controller. It was initially developed to increase the apparent size of the collector array, by producing the same temperature gain (ΔT) across its fluid circuit and was produced across the collectors. Thus by means of temperature sensor, a pseudo collector controller, and a temperature control valve, the pseudo collector was "slaved" to follow the collector output.

In the present experimental design, the real collector array is completely bypassed (valve PVI in figure 1 is closed) and the temperature gain (ΔT) across the pseudo collector is reproducibly controlled by a programmed temperature curve. A strip chart recorder has been modified so that a light-diode device follows a profile curve of ΔT as a function of time, the curve having previously been calculated and inscribed on chart paper. An output voltage proportional to ΔT is thereby generated. This method has been used in experimental runs to date.

A second method has also been devised to calculate collector response. A microcomputer, a hp 9825A is used to calculate ΔT on-line. Using a standard collector response subroutine and using the climatological data as provided on the weather tape, an output voltage proportional to ΔT is generated in the multi-programmer D/A converter, and transmitted to the pseudo collector controller. This is the principal control method that will be used in future experimental runs. In either case, the voltage signal is used to drive the pseudocollector control circuit, which is completely independent of the solar system controller. The solar controller cannot distinguish whether the real collector or the pseudo-collector is being used.

THE LOAD SIMULATOR

The building load subsystem is shown in Fig. 6. The load simulator is intended to reproduce the response of a building being heated or cooled by the solar system. The hardware consists mainly of the hp 9825A microcomputer; it issues ON/OFF control to an air conditioner when the inlet air temperature is too high, or provides an analog signal to the SCR control for the duct heater when the inlet air temperature is too low.

A building load model is used to calculate, on-line, the building internal air temperature. Initially a simple linear response load model will be used; however, plans call for eventually including dynamic building and thermostat responses. Inputs to the program include measurements of the energy (flow rate plus temperatures) supplied to the heating or cooling coil by the solar system load loop, climatological values from the weather tape, building envelope parameters, thermostat response model, and the thermostat set points. Building parameters from the standard DOE load tape will be used. The resulting calculated inlet air temperature is reproduced as actual temperature of the air streaming across the heating and cooling coil by controlling the above-mentioned air conditioner and heater located upstream in the air duct. The only microcomputer output used by the solar controller is a signal when a thermostat set point is crossed, thus being equivalent to the function of a room thermostat.

INSTRUMENTATION AND DATA ACQUISITION

Solid-state temperature sensors are used to generate the input signals for the solar controller, and thermocouples are used for data acquisition purposes. Liquid flow rates are measured with accurate turbine-type flow meters. Air temperature and flow measurements are made in the building load ductwork; however, these measurements are less accurate than the liquid ones and are used only for checking purposes. Gas meters and electric meters are used to monitor auxiliary energy usage. A schematic of the instrumentation is shown in Figure 7. A 100 channel datalogger is used to gather and printout the data. It is interfaced to the microcomputer, so that some on-line data reduction is carried out, with the results also being printed. A single microcomputer is being used for all the purposes described in this paper.

ERROR REQUIREMENTS AND SOURCES

Measurement errors must be small and well-known in order to conduct meaningful tests of alternative control strategies. A goal of 3 to 5% has been set for heat balance accuracies, requiring individual measurement errors of 2% or less. In addition to the basic component resolution, other sources of error include calibration, electronic noise, signal drift, heat loss calculations and the storage tank model. The last two items are particularly difficult, as they require an adequate empirical characterization of system components. All components, especially including the piping, are sources of heat loss to ambient. The storage tank temperature is measured at several locations within the tank. However, an accurate model of the entire tank is a requisite, as the change in stored energy is usually a significant term in any energy balance calculation.

RESULTS TO DATE

Heat balance experiments conducted earlier this year showed that accuracies of 6 to 7% were being

achieved. This fell short of our goals of 3 to 5%, and indicated a lack of sufficient knowledge of the storage tank performance as well as unacceptable errors in the temperature measurements. The revised measurement of the storage tank temperature distribution and the introduction of an amplifier for the thermocouple signals have both helped to reduce measurement errors. New heat balance experiments are currently underway to determine how successful these improvements have been. A recent experimental run, as shown in Table 1, indicates a measured heat balance error of 3.7%, compared to an earlier error of 7.6%.

Much time has also been spent during the past few months in completing and debugging the load simulator. This is now completed except for the interface to the weather tape.

The actual experiments to compare the performance and cost-effectiveness of alternative control strategies have not yet begun.

PLANNED ACTIVITIES

The highest priority is to obtain data on the energy use of different control algorithms using the present controller. Beyond that, modifications to the system and controller are planned that will accommodate testing of variable flow strategies. In the longer term, if justified by project results, the experimental capabilities can be expanded to include additional components, such as heat pumps, chillers, and cold-side storage.

TABLE 1. HEAT BALANCE EXPERIMENTS

	HEAT IN	HEAT TO LOAD	HEAT LOSS	Δ STORAGE	HEAT BALANCE	% ERROR
PREVIOUS RUN	210.7	754.4	55.7	-542.2	-57.1	-7.6
NEW RUN	205.5	923.7	61.0	-744.1	-35.1	-3.7

NOTES: Heat is given in units of megajoules (10^6 J).

$$\text{Heat Balance} = \text{Heat In} - \text{Heat to Load} - \text{Heat Loss} - \Delta\text{Storage}$$

$$\% \text{ Error} = 100 \times \frac{\text{Heat Balance}}{\text{Heat In} - \Delta S}$$

$$\text{Where } \Delta S = \Delta\text{Storage, If } \Delta\text{Storage} < 0 \\ = 0 \quad \text{If } \Delta\text{Storage} \geq 0$$

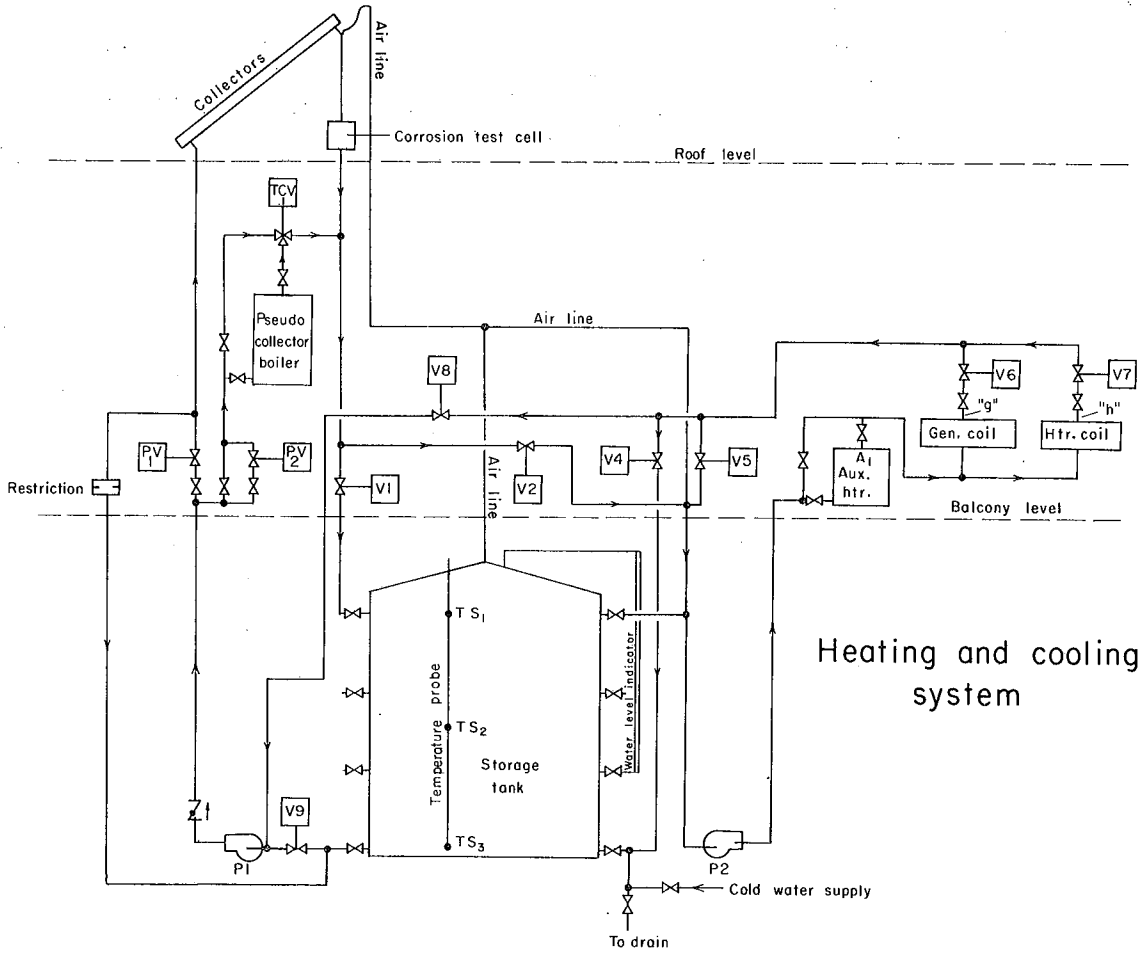
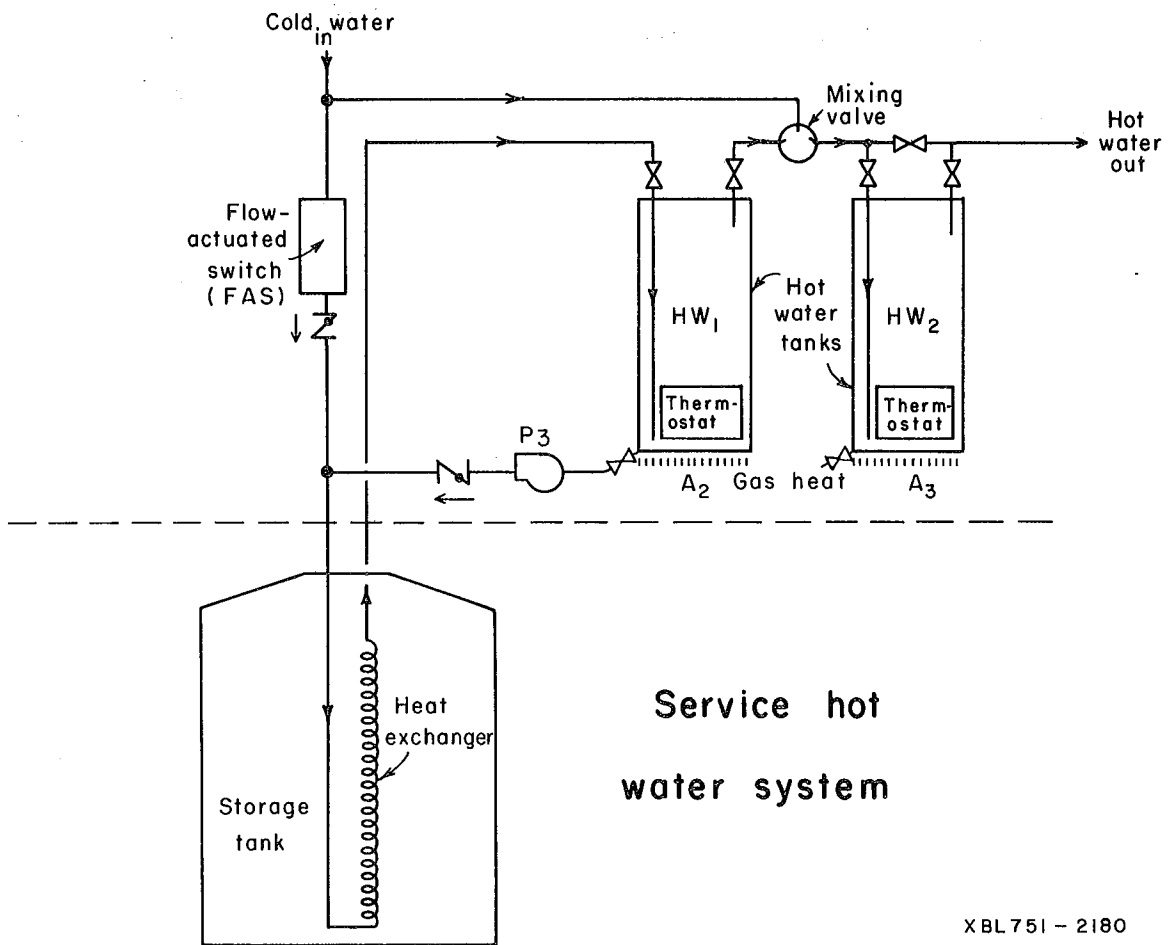


FIGURE 1

XBL75I - 2178



**Service hot
water system**

XBL 751 - 2180

FIGURE 3

SOLAR CONTROLLER

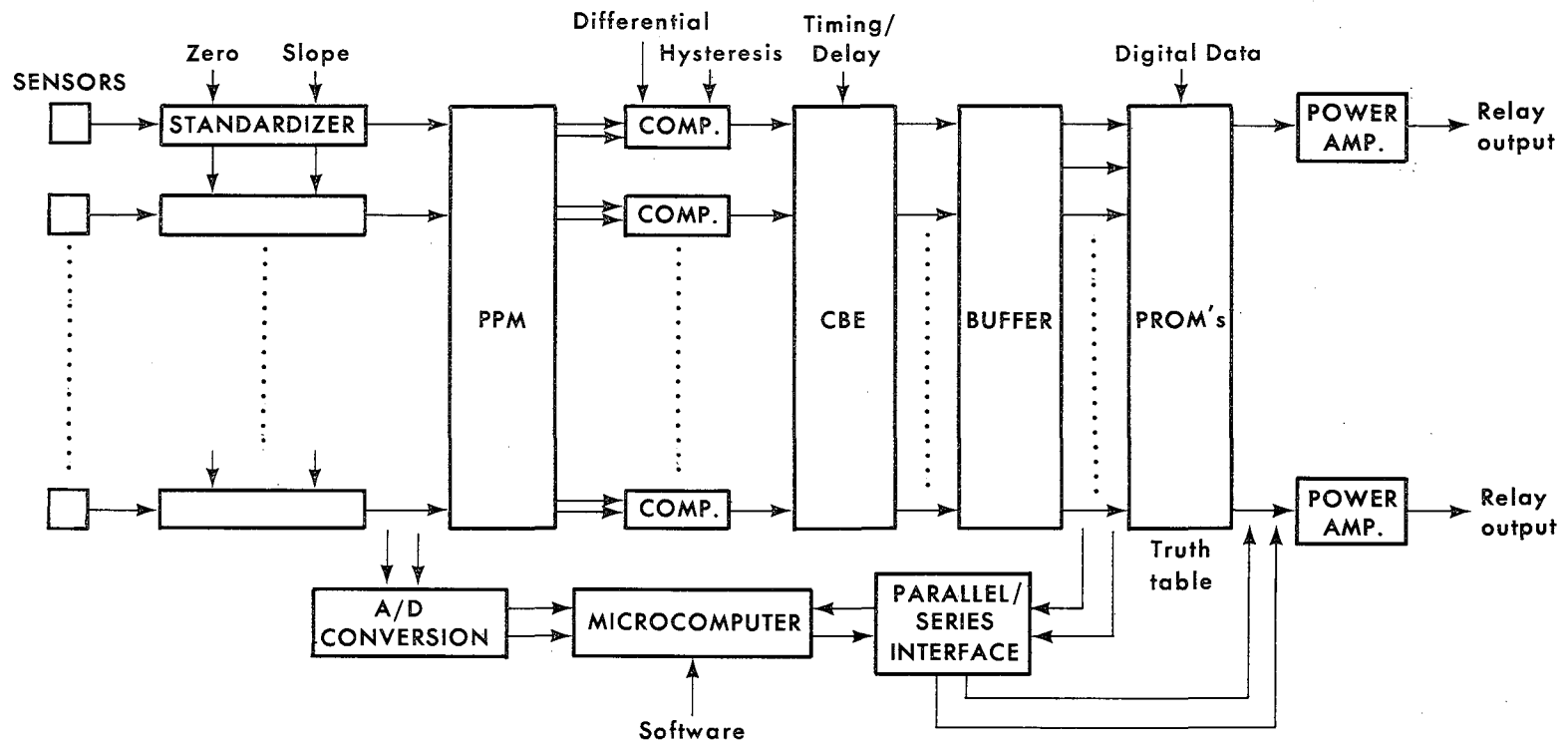


FIGURE 4

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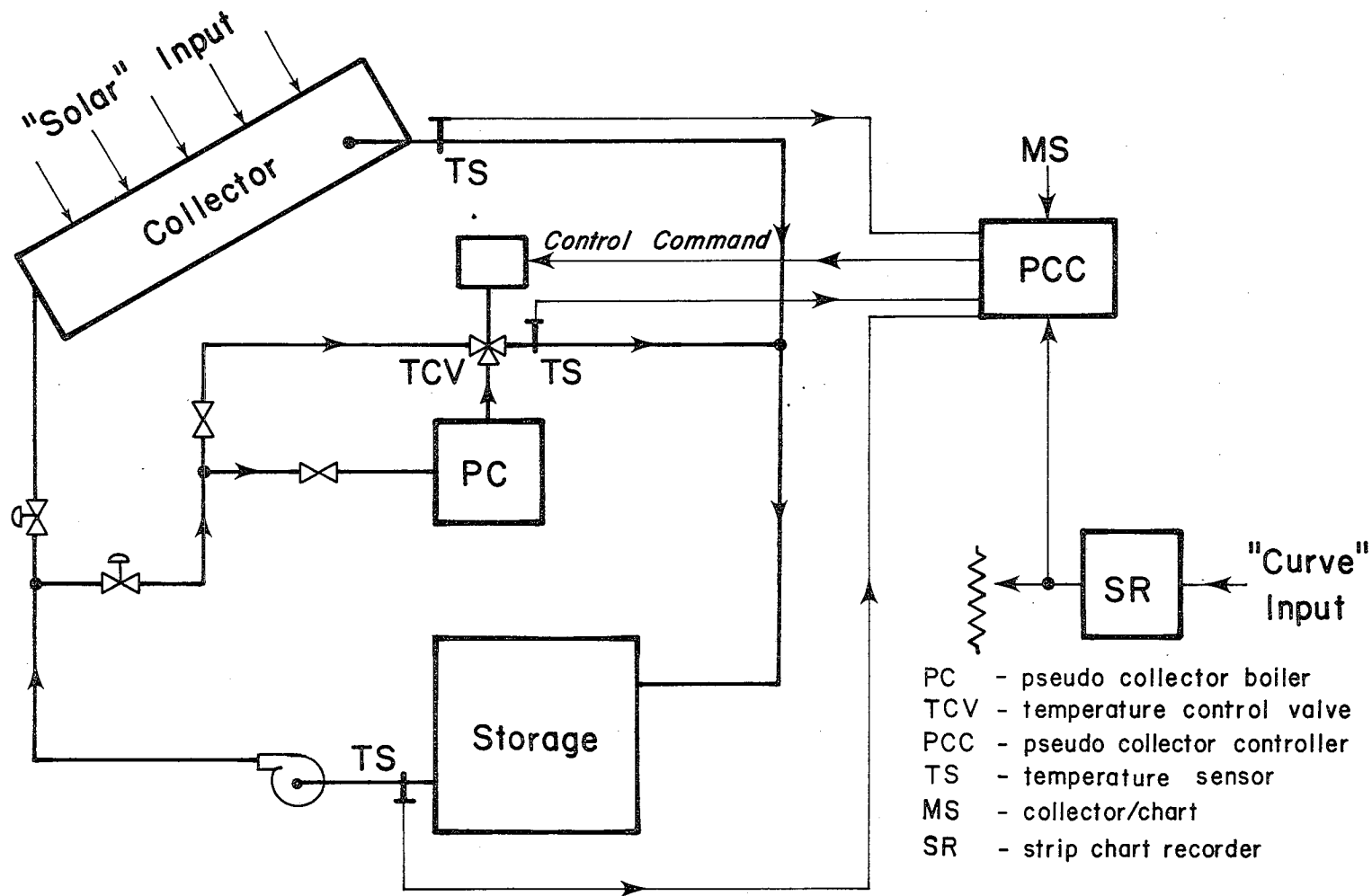
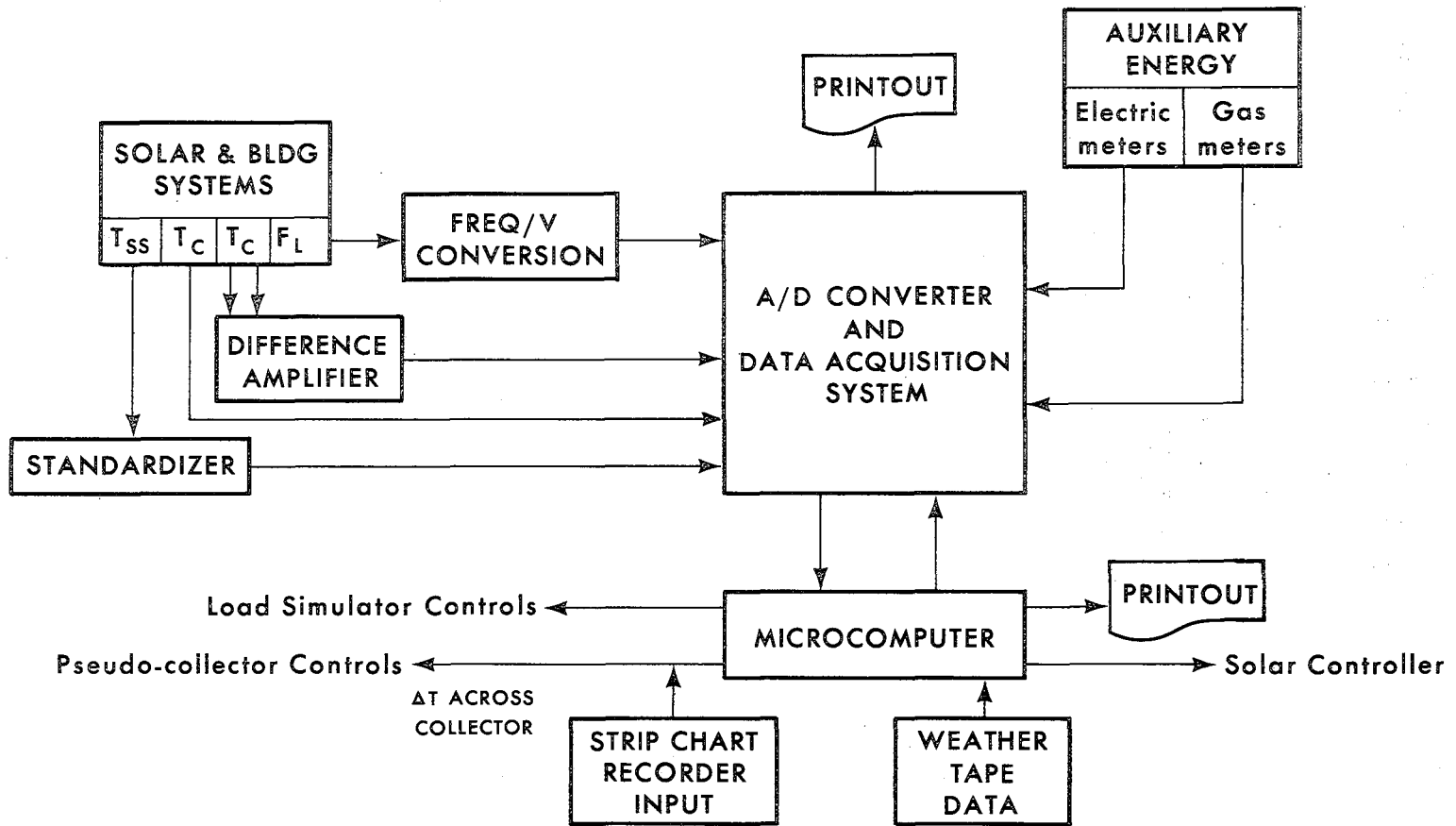


FIGURE 5 The heat input simulator, the pseudo collector system. XBL784-618

INSTRUMENTATION



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FIGURE 7 Instrumentation and data acquisition diagram.

XBL 785-885

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