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Electronic Controller Development and Evaluation of Control Strategies

Michael Wahlig and Mashuri Warren

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Lawrence Berkeley Laboratory University of California/Berkeley

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ELECTRONIC CONTROLLER DEVELOPMENT AND EVALUATION OF CONTROL STRATEGIES*

LAWRENCE BERKELEY LABORATORY
Contract Number
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OBJECTIVE

This project has three main objectives: 1) the development of a relatively inexpensive electronic controller that will be capable of operating a solar heating and cooling system in a near-optimized manner; 2) use of this controller and the LBL experimental solar controller test facility to compare experimentally the value of alternative control algorithms under a variety of input meteorological conditions and output load demands; and 3) determination of the relative performances of this controller and more complex control systems.

BACKGROUND

The controller being developed is intermediate in complexity and cost between the simple, low-cost differential thermostat type and the elaborate, higher-cost microprocessor-based models. It would control system operation according to a preprogrammed algorithm that translates operating state conditions (e.g., fluid temperatures or switch positions at various locations in the heating and cooling system) into a set of operating instructions (e.g., open or close valves, turn pumps on or off). The control algorithm is contained in a Programmable Read-Only Memory (PROM) chip that is a discrete plug-in component in the electronic circuitry. Therefore, the operating algorithm can be changed by simply interchanging this integrated-circuit (IC) component. An experimental solar heating and cooling system was designed and constructed to test and exercise the controller. This heating and cooling system serves as an experimental facility for testing the performance of alternative control algorithms for a variety of input meteorological conditions and output load demands. The relative performance of different types of controllers can also be quantitatively determined using this experimental facility. The measure of performance is the amount (and cost) of the auxiliary back-up energy saved for different control strategies. The experimental evaluation of the cost-effectiveness of alternative controllers and control strategies is expected to be the primary output of this project. The development of the controller and the experimental facility have been described in detail elsewhere.[1,2,3,4]

SUMMARY

The major activities during FY 1978 involved improvements of the experimental test facility. The facility is being equipped with simulators for the heat from solar collectors and for the building load, driven by the same input meteorological data. Instrumentation has been added to the facility, and heat balance tests using solar collector and simulator heat input have been carried out. In addition, heat loss experiments have been conducted without any heat input or load. The TRNSYS computer program was employed to predict system performance and the results were compared with experimental measurements. Recent work is described in reference 5.

TECHNICAL ACCOMPLISHMENTS

Instrumentation. A major development in FY 1978 was the implementation of the data acquisition and experiment control system. An hp-9825A microcomputer arrived in November 1977 and has been interfaced with the 100 channel data logger, with the multiprogrammer, and with the solar controller. The microcomputer will perform four major functions in future experiments: 1) data acquisition and on line data reduction, 2) building load and response simulation, 3) solar collector response simulation, and 4) controller status monitoring and microcomputer override. Additional memory, for a total of 24 kbytes, was installed in August 1978. All thermocouples and temperature sensors have been wired into the data logger and are available to the microcomputer for data acquisition and experiment control. The microcomputer incorporates building and collector response models. Meteorological and insolation data are required to solve the response model equations and the standard DOE weather tapes for the various regions can be used to generate these inputs. Thus the experimental facility can be operated under diverse simulated weather and load conditions to test solar control strategies.

Collector simulator. A "pseudocollector" boiler was part of the initial facility design. The boiler output passes through a temperature control valve that allows precise adjustment of the output temperature. In the initial design the pseudocollector was "slaved" to follow the output of the roof collector array. However, reproducibility of experimental conditions is essential for quantitative comparison of the performance of alternative control strategies, so the collector output is now simulated. An electro-mechanical collector output simulator tracks a programmed temperature curve on a stripchart recorder to define the pseudocollector output. In future experiments the microcomputer will generate the output temperature information for the pseudocollector using solar insolation data, weather data, measured system parameters, and a standard collector response model. In this way a wide range of reproducible system input conditions can be simulated.

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Building load simulation. The fabrication of an automated "pseudoload" air flow channel, designed to simulate the air flow across the heating or cooling coil in the furnace ductwork in a residential system, is nearly completed except for delivery of two safety switches. This subsystem construction has been one of the major FY 1978 tasks. The purpose of the load simulator is to provide a controlled and reproducible residential building load isolated from the inappropriate laboratory environment in which the solar system is actually located. Both heating and cooling loads can be simulated. The temperature within the ductwork is carefully controlled by an electric duct heater and an air conditioner. The microcomputer gives an on/off control signal to the air conditioner if the inlet air temperature is too high, and gives a proportional control signal to the duct heater if the air temperature is too low. Using weather data and a building load response model the microcomputer will also calculate load demand information; thus the microcomputer will serve as the demand thermostat for the controller.

Computer modeling. The TRNSYS program was used to calculate system performance for comparison with experimental measurements. Comparisons were made for several different modes of the solar system operation, and, in general, agreement between measured and calculated values was quite satisfactory. Somewhat less close agreement was observed for low flow conditions when only the heat input subsystem was involved (no load). Efforts have been made to improve the model for such low-flow modes of operation by revising the method of representing the storage tank. Simple controllers were also studied with the computer model. A study of on/off controllers with low offset and hysteresis values ran into numerical convergence problems. Similar problems developed in studies involving proportional control schemes. Only on/off controls with fairly high offset (20°C) and low hysteresis (1.5°C) settings ran successfully. Realistic flow-rate values were used throughout the runs. The static equations used to describe components in TRNSYS apparently caused the convergence problem. To study the control algorithms more precisely and realistically, some TRNSYS equations may need to be modified to include short-term dynamic effects. This problem is now being addressed by researchers at Drexel University and at the present time we have no plans to pursue this computer modeling of control algorithms.

Heat balance tests. The energy flows from the collector loop and from storage should exactly balance the energy flows to the load, to storage, and loss to the ambient air. The heat input and load subsystems were monitored carefully. Precision flow and temperature measurements were recorded and used to calculate heat quantities over time intervals of typically 5 to 15 minutes. Efforts were made to control and/or monitor all heat flows within the system. The storage tank lid was resealed to eliminate vapor losses. The collector draining system was modified to prevent mixing air with the return fluid, so that uniform heat exchange and flow conditions would persist throughout the experimental runs. The thermal characteristics of the fluid were measured and the storage volume was determined and periodically checked. Extensive heat loss measurements were used to derive an empirical heat loss equation as a function of the temperature difference between the central axis of the storage tank and the ambient air. The error in heat balance, defined as the unaccounted-for energy flow divided by the incoming energy flow, depends critically on the accuracy of the flowrate and temperature measurements. The digital flow rate measurement is accurate to less than 1%. The calibrated temperature sensors are accurate to ±0.1°C. The copper-constantan thermocouples were found to be accurate to about ±0.5°C. Wiring the thermocouples in pairs produced temperature difference measurements accurate to about ±0.1°C. The average error in heat balance for the initial set of day-long experimental runs was about 7% with a spread of 1% to 12% for individual runs. The goal has been to reduce these errors to 5% or less, so that the auxiliary energy use for various control strategies can be determined to within 5%. Experimental tests incorporating improvements to the instrumentation that were run during the latter part of FY 1978 indicate that this is a realistic goal.

FUTURE ACTIVITIES

Contract activities. Upon completion of the building load simulator, the experimental evaluation of alternative control algorithms will begin. The first series of test runs will compare system performance for a reasonable set of algorithms using the LBL-developed controller. The experimental program will then expand to include proportional flow modes. Modifications to the controller and to certain actuators should allow testing of proportional flow algorithms, and thus their comparison with on/off strategies. Plans also call for the testing of commercially-available controllers. The experimental program of testing the performance (and calculating the resulting economics) of alternative control strategies will continue throughout FY 1979. Comparisons of simple on/off vs. simple proportional controllers should be followed by the testing and evaluation of more complex operating strategies, using microprocessor controllers. One of the objectives will be to determine whether optimized control strategies are cost-effective for the operation of fairly simple solar systems scaled for residential buildings. By FY 1979, controller investigations by several other groups should be completed or in advanced phases. LBL will seek to identify and carry out tasks that would complement and enhance the productiveness of these other projects; e.g., by testing advanced controllers or new control strategies.

Post-Contract activities. Following successful operation and evaluation of the LBL-developed electronic controller, steps will be taken to transfer this technology to the commercial sector. The advice of consultants with experience in the controls industry will be used in this task. The possible applications of this type of controller for non-solar uses, such as for energy conservation in commercial or industrial buildings, will also be explored.

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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720