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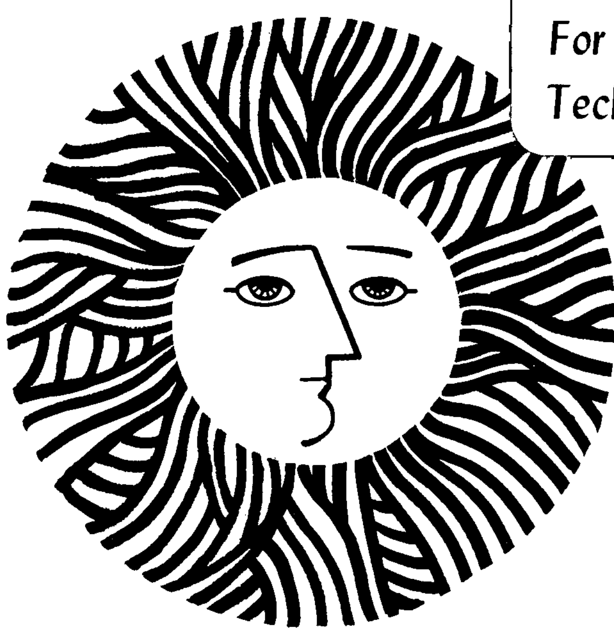

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CONTROLS FOR SOLAR HEATING AND COOLING*

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Contract No. W-7405-ENG-48

OBJECTIVES

The LBL solar controls program has three principal objectives: To use the LBL test facility to evaluate experimentally the relative performance of different solar heating control strategies for a variety of input meteorological conditions and output load demands; to analyse problems in the control of active solar systems that effect system performance and reliability and carry out theoretical studies of collector and load loop performance in support of the experimental work; and to perform technical support activities as part of the Department of Energy (DOE) solar heating and cooling R&D program. Program support tasks include program planning, preparation and evaluation of solicitations, proposal reviews, and technical monitoring of DOE solar contracts.

DESCRIPTION OF WORK

The experimental test facility was constructed to evaluate the operation and performance of active hydronic solar energy system control strategies and equipment. The facility consists of a collector loop heat input simulator, a storage tank, a load loop air channel with fan coil, an auxiliary heater, and associated pumps and valves. Only the apparent temperature of the collector and the load demand thermostat condition are simulated, enabling control strategy and equipment comparisons based on identical meteorological and load conditions. The facility is described in detail elsewhere [1,2,3,4].

This year the experimental test facility was operated to simulate a specific residential solar assisted heating system for several days, using both simulated weather and typical meteorological year (TMY) weather and insolation data for Madison, Wisconsin in January. The residential building loads are calculated using incident insolation, along with the TRNSYS and are used as inputs, to drive the experimental system simulation. Early in the year a number of four hour and one day experiments were repeated to verify operation and energy balance of the collector loop and of the load loop separately. At the end of the year a number of two day experiments using TMY year data were run.

The performance of a solar system during a particular day is dependent on the insolation, ambient temperature (which determines collector losses and building load), and the system's performance during the previous day as indicated by the starting storage tank temperature. A knowledge of what will happen on the next day is also important to measure the utilization of energy collected on a particular day. The weather and insolation patterns for January in Madison and hourly storage tank temperatures predicted by TRNSYS for January were examined to determine categories such as high amount of insolation, low ambient temperatures, and poor previous day. Two pairs of days were chosen for detailed test facility simulation: a "bad-good" series and a "good-bad" series.

Performance indicators, used for evaluating solar systems, include: collection efficiency, system thermal efficiency, solar coefficient of performance, system overall efficiency, and solar fraction. In addition, the change in storage tank temperature indicates the extent to which available solar energy is taken from or added to the storage tank over a given period.

Test Facility Results

Experiments were run using simulated meteorological and load inputs to evaluate experimental repeatability and verify system energy balances. Experiments also compared two control strategies: a storage-coupled heating mode and a direct collector to load heating mode. In the storage-coupled heating mode, collectors heat the storage tank and energy is drawn from storage to heat the load when available and needed. With the direct heating mode, the collectors can supply heat to the load without going through the storage tank. The direct heating mode requires additional piping, valves, and control.

Table I shows results from test facility experiments. The quantities used in the tables are defined as follows: building load (QLOAD), auxiliary energy for load (QAUX), the natural gas usage (GAS), solar energy delivered to the load (QSOLAR-LOAD), insolation onto the collector (QI), collected energy (QC), predicted collected energy (QC_{th}), storage tank losses (SLOSS), load loop piping losses (LLOSS), collector loop piping losses (CLOSS), parasitic energy used (PARA), average storage tank temperature (T_{tank}), stored energy (QS), and change in stored energy (DQS).

Table I shows typical one day summaries for a cold January day in Madison, Wisconsin with good insolation. The 24 hour system energy balance is within 2 %, indicating good accounting of energy flows in the collector and load loops and in the storage tank. This energy accounting is done minute by minute as the experiment progresses. Energy flow quantities are calculated from measured temperatures and flow rates. Energy losses are calculated from measured fluid and room temperatures and experimentally estimated loss coefficients. The parasitic and auxiliary gas consumption are measured with standard utility meters interfaced to the experiment instrumentation.

Test days were run twice for each of two different control strategies: direct heating and storage-coupled heating. The different runs show excellent agreement in the load demand, QLOAD, the total energy inputs to the system, Qin, the total energy output from the system, Qout, and the energy balance, Q. The energy loss terms, SLOSS, LLOSS, and CLOSS also agree well from run to run. However, there is some variation from run to run in the auxiliary energy usage, QAUX, in the change in stored energy, DQS, and in the contribution to the load from solar, QSOLAR-LOAD. This variation is of the order of 25 MJ over the day and represents less

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Table I. Comparison of Test Facility Runs with TRNSYS Simulation for January 18 in Madison, Wisc., a cold weather day with good insolation.

Quantity Strategy	Units -	Run 7 Direct	Run 11 Direct	Run 8 Storage	Run 12 Storage	TRNSYS Series
Time	hr	0-24	0-24	0-24	0-24	408-432
$Tamb_{avg}$	oC	-10	-10	-10	-10	-10
Initial T_{tank}	oC	31.1	31.5	31.1	31.6	31.2
Final T_{tank}	oC	32.5	33.3	32.3	32.4	36.4
Change T_{tank}	oC	1.4	1.8	1.2	0.8	5.2
DQStank	MJ	24.7	32.8	21.0	14.6	94.7
SLOSS	MJ	27.6	27.4	27.4	25.6	35.4
QLOAD	MJ	517.8	517.9	517.9	517.3	514.6
LLOSS	MJ	38.6	38.5	36.0	32.1	24.2
QAUX	MJ	234.5	248.0	230.5	204.9	268.3
QI	MJ	831.0	831.0	832.1	831.5	831.4
QC_{th}	MJ	410.7	401.1	424.0	428.5	421.8
QC	MJ	390.7	388.7	386.8	412.5	421.9
CLOSS	MJ	12.4	11.8	11.8	11.2	15.6
PARA	MJ	32.7	30.9	33.4	31.9	-
Qin	MJ	600.5	603.9	596.3	602.8	595.5
Qout	MJ	596.4	595.6	593.1	586.2	589.8
Balance (ΔQ)	MJ	4.1	8.3	3.2	16.6	5.7
Balance (%)	-	0.7	1.4	0.5	2.8	0.97
QSOLAR-LOAD	MJ	321.9	308.4	323.4	344.5	270.5
Solar to load	%	62	60	62	67	53

than 5 % of the total energy flow during the day which was the accuracy goal for measuring energy flows in the test facility.

Comparison of Test Facility Results with TRNSYS

To assist in evaluating the results obtained from the test facility, TRNSYS simulations are run for the same test days. The TRNSYS simulation was started on January 1 at 1 AM, using TMY weather data, with a storage tank temperature of 20 ^{o}C, and run continuously for the entire month. Initial average storage tank temperatures and time dependent building loads, as determined by TRNSYS for a given period, were then used for the experiments.

The test facility operating strategy uses an auxiliary heater to boost the temperature of the water to the fan coil as long as the return water temperature is not greater than the storage tank bottom temperature. Existing TRNSYS modes for parallel and series auxiliary heating do not model this operation. The parallel mode unrealistically draws the storage tank down to room temperature, thus underestimating the auxiliary energy consumption. The series auxiliary heating mode of TRNSYS draws the storage tank temperature down until the storage can no longer satisfy the building heating requirements. It then switches to an auxiliary only mode. This is closer to typical control action and is used to model the test facility. For identical conditions in Madison the TRNSYS parallel auxiliary mode used only 9424 MJ of auxiliary energy while the TRNSYS series auxiliary mode required 11060 MJ of auxiliary energy to meet the January heating load.

Table I compares energy flows predicted by TRNSYS with the direct heating and the storage-coupled heating modes run on the test facility. The solar energy collected, (QCth), as predicted by the test facility simulation Hottel-Whillier-Bliss collector model, agrees well with the TRNSYS simulation for clear days with good insolation, although in the direct heating mode the collector loop tends to be on for a slightly shorter time. For both modes, the pseudocollector boiler system delivers slightly less energy (QC) than predicted. This may be due to a limitation in the boiler output control.

Differences between the TRNSYS simulation and the test facility direct and storage strategies indicated in Table I include: the change in stored energy; the load loop piping losses; the load handled by solar; and the auxiliary energy. As expected, the test facility boost mode of operation increases the system performance slightly by using the stored solar energy at slightly lower temperatures than the TRNSYS series mode.

The energy input to the system for the TRNSYS and test facility runs, Qin, (energy from the collectors, from auxiliary, and from storage) agrees very well, as does the energy output, Qout (energy to the load and all losses). The overall energy balance is quite good for all of the 24 hour runs. The only discrepancy of note is the solar contribution to the load which varied an average of about 10%. Parasitic energy for the control valves, pumps, and fans is not accounted for in the TRNSYS simulation.

Comparison of Storage Coupled and Direct Heating

A series of experiments was conducted using both direct heating and storage-coupled heating modes using real weather and insolation data for two January days in Madison, Wisconsin. Table II indicates the difference in the performance between the two strategies for these two days. Solar coefficient of performace (SCOP) is the ratio of the solar energy utilized by the load to the parasitic energy required to run the solar system. Solar fraction is the ratio of the solar energy utilized by the load to the total load. As indicated in the table, no significant difference exists between the control strategies for these days. Both modes of test facility operation utilize greater energy from storage than predicted by the TRNSYS simulation, as indicated by the storage tank temperature change. To determine long term comparisons, more testing would be required.

Table II. Comparison of two-day runs of test facility for direct heating and storage coupled heating modes for identical building load and meteorological conditions (January 18-19 in Madison, Wisc.). TRNSYS results are included for comparison.

Quantity		Direct Run 7	Direct Run 11	Storage Run 8	Storage Run 12	TRNSYS
QC/QI	Collection efficiency	35.5	36.3	37.7	40.3	43.4
QSOLAR-LOAD / QI	Thermal efficiency	39.0	42.0	42.0	46.1	37.6
QSOLAR-LOAD / PARA	SCOP	7.3	8.3	7.4	8.8	-
QSOLAR-LOAD / QLOAD	Solar fraction	45.3	48.7	48.8	53.5	43.4
ΔT_{tank}	Storage change (^{o}C)	-4.8	-6.4	-5.4	-7.2	-1.0

Theoretical Studies to Support Experimental Program

During FY 1980 work was completed on modeling of collector loop dynamics[5,6]. A model of a residential building, a fan coil heat-delivery system, and a bimetal thermostat to simulate the effects of heat input on room air dynamics, has been applied to examine the building thermal behavior in response to heat input from an active solar space heating system[7].

The effects of the variable storage tank temperature, of outdoor temperatures, and of fan coil sizes on the cycling rate, on the on-time and off-time of a heating cycle, on room air temperature swing, and on offset of the average air temperature from the setpoint (droop) are determined by computer simulation. Heat input is provided directly to the air as, for example, when a heating fan coil is turned on.

For given conditions of outdoor temperature, anticipation, and thermostat setpoints, the storage tank temperature has a direct effect on swing as shown in Figure 1. The droop, the offset of average room temperature from the setpoint, also depends on the amount of thermostat anticipation and on the heat delivery duty cycle. The higher the storage tank temperature, the larger is the swing in room temperature and the smaller is the droop. Results indicate that to maintain room temperatures within comfort limits by minimizing both swing and droop, a hydronic solar space heating system requires a control system that adjusts anticipation and setpoints in relation to the outdoor and the storage tank temperatures. This will require more than a simple on-off bimetal thermostat.

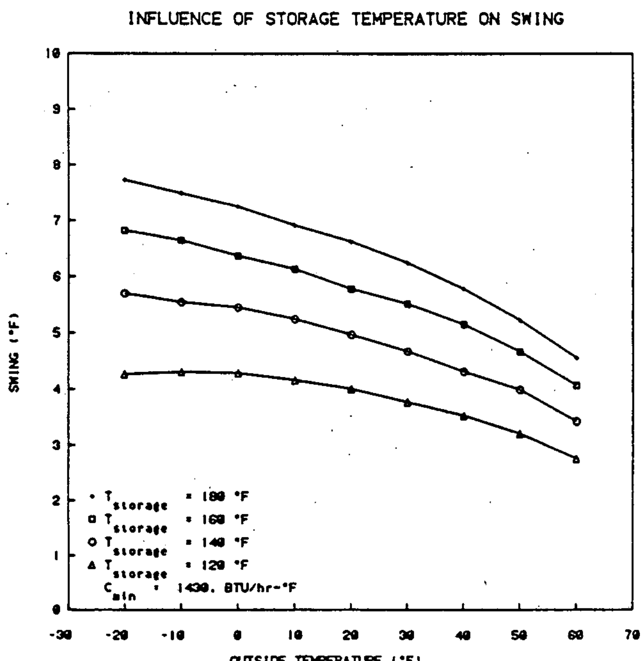

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Figure 1. Solar storage tank temperatue influences room air temperature swing. As the storage tank temperature decreases, the swing decreases for a given outside temperature.

Technical Support Activities

This past year the laboratory has been actively involved in proposal review and contract monitoring for the Controls Element of the DOE solar heating and cooling R & D program. Activities have included coordination with SERI, conducting project reviews, and reviewing the reports of DOE controls contractors.

TECHNICAL ACCOMPLISHMENTS

- Several two day "typical day" experiments were run on the test facility using TMY weather data.
- Comparison of test facility results shows poor agreement with TRNSYS simulation in the parallel auxiliary mode, but good agreement in the series auxiliary mode. The test facility operates in a series boost mode.
- Solar heating system operation with two different operating strategies were run: direct collector to load heating and storage-coupled heating. No significant improvement in system performance was found for the direct heating strategy.
- Simulation analysis of the interaction of the solar heating system with the building load and thermostat was completed and presented. The analysis indicates that, using a conventional room thermostat, large temperature swings can be expected when the storage tank is charged to a high temperature.

FUTURE ACTIVITIES

The experimental test facility work has been concluded.

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CONTRACT INFORMATION

Period of Contract: Begin 7-74, End 9-80.

FY80 Funds: $220K.

Total value of contract: $785K.

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