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DYNAMIC PERFORMANCE OF A PROTOTYPE SOLAR-ASSISTED HEAT PUMP

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ABSTRACT

A prototype water-air solar assisted heat pump (SAHP), built by Northrup Incorporated has been tested at BNL as part of a DOE sponsored contract for the "development of marketable solar assisted heat pumps." The steady state test results indicate that the nominal performance goal for the prototype, COP of 6 at 90 F entering water temperature, was achieved.[1] The transient and cycling tests of the Northrup prototype are described in this report. Tests were performed while the unit cycled under a conventional and modified control mode. Results indicate that cycling performance can be significantly enhanced by operation under the modified control mode where the supply fan is run after the compressor is turned off to extract heat still available at the end of the duty cycle.

INTRODUCTION

A prototype water-air heat pump designed for use in solar assisted heat pump (SAHP) systems was constructed by Northrup, Inc. as part of a contract awarded by the U.S. Department of Energy (DOE) for the "Development of Marketable Solar Assisted Heat Pumps." The final phase of the effort included the testing of the prototype by Brookhaven National Laboratory (BNL). A nominal performance goal for this prototype was set early in the period of the contract. This goal was a steady state coefficient of performance (COP) of 6 at 90 F entering water temperature. The steady state tests of the unit have been completed and show that this goal has been achieved. The results of this steady state testing are reported in references 1 and 2.

The dynamic tests of this SAHP prototype are important because the results comprise a proven heuristic heat pump component model for use in SAHP system simulations. In addition, the results demonstrate the merit of a control scheme which promises to improve cycling performance.

Features of the final Northrup design are:

(1) 1-1/2 ton and 2-1/2 ton rotary compressors with common suction and discharge lines and separate accumulators;

(2) Coaxial evaporator with refrigerant in the inner line;

(3) Three row slanted air-cooled condenser;

(4) An electric expansion valve;

(5) Cooling is achieved via a separate water/air heat exchanger which receives chilled water from the heat pump, the condenser being cooled by outside air.

The transient tests of the Northrup prototype SAHP were performed using the BNL Solar Heat Pump Simulator, a device which creates realistic operating conditions and provides for the determination of the performance of liquid-air and liquid-water heat pumps. The three subsystems of the simulator as they were arranged for transient testing of the Northrup prototype are depicted semi-schematically in Figure 1.

The Air Load Subsystem provides for measurement and control of all conditions pertaining to the "air side" of the heat pump. The Water Load Subsystem is used by the Air Load Subsystem to withdraw heat at the heat pump's supply side via an air/water coil, at a rate which is controlled to keep the

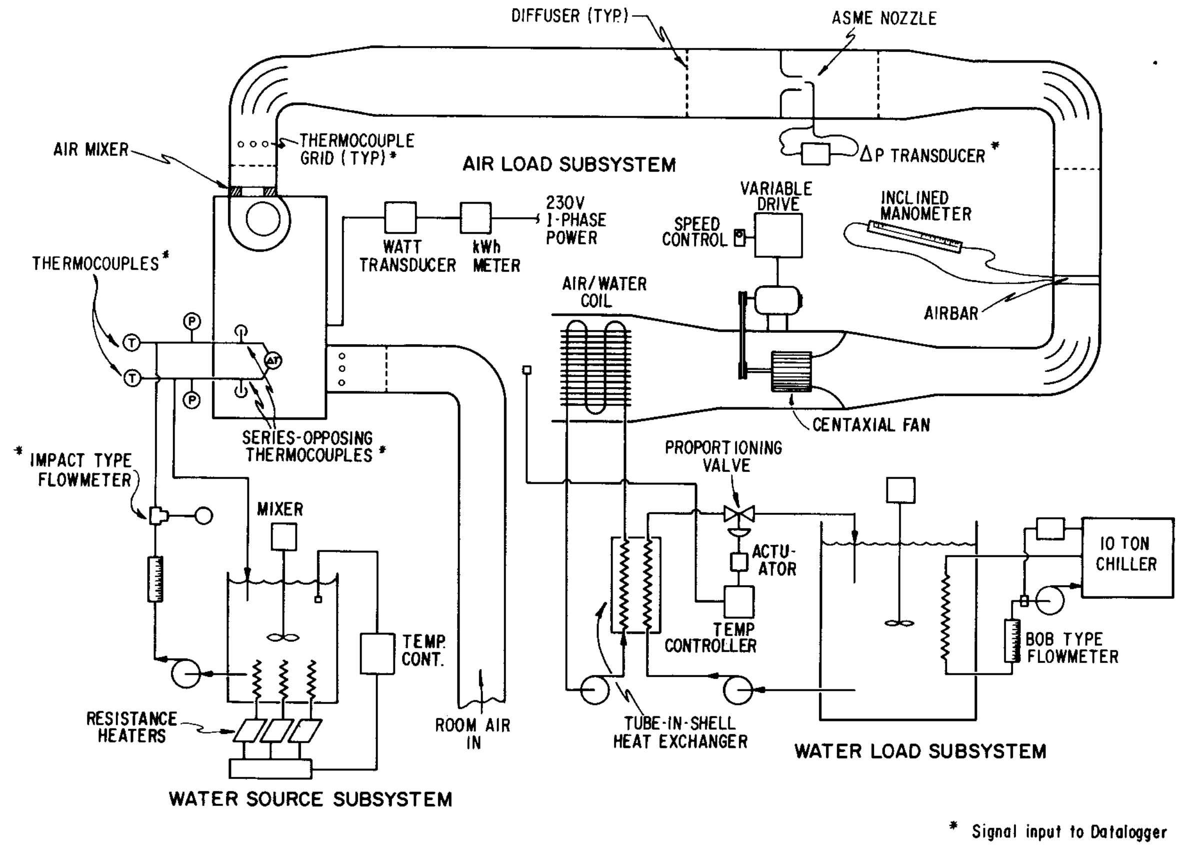

Figure 1. BNL Simulator Air Load Subsystem Used to Test Northrup SAHP

temperature of the room air which is returned to the unit at a constant temperature (usually at residential space temperatures of 20 to 21 C (68 to 70 F). All instrumentation and procedures followed closely the recommendations of ASHRAE.[3]

Transient and cycling tests were performed with entering water temperatures of 90, 70, and 50 F circulated through the evaporator at 9 gpm. The entering air temperature was maintained at 70 $\pm$ 0.2 F at a flowrate of 1100 SCFM. Power was supplied at 230 $\pm$ 0.5 volts. All data were recorded in a period of 5 seconds by a datalogger at a frequency of 2 scans per minute. Details of the instrumentation employed may be found in references 1 and 2.

The integrated COP at a given point in time is the integrated heating capacity divided by the integrated compressor power. The heating capacity during each record interval was assumed to be constant and equal to the average of the instantaneous capacities measured at the beginning and the end of each interval. The compressor power consumption during each interval was assumed to be constant and equal to the instantaneous power measured at the end of the interval.

That is:

$$\text{Integrated COP} = \sum_{i=0} [(Q_i + Q_{i+1})/2] \Big/ \sum_{i=0} W_{i+1}$$

where: Q_i = instantaneous heating capacity at time 30i seconds from startup

W_i = instantaneous compressor power consumption at time 30i seconds from startup.

COLD START TRANSIENT TESTS

For the cold start transient tests the unit remained inoperative for a period greater than 2 hours. The external conditions were already established at the time the unit was energized. The unit was run for 15 minutes at which time the compressor was turned off. The fan was left running and data were recorded until such time as the integrated COP began to fall (i.e., the residual heating capacity did not justify the required fan power). The cold start transient runs were performed at 50, 70 and 90 F entering water temperature. Examples of test results for these runs are given in Figures 2, 3, and 4 for the respective entering water temperatures. Important observations from these results are:

(1) Steady state is reached within approximately 3 minutes of start up;

(2) The integrated COP is from 75 to 80% of the steady state value at the time steady state is reached;

(3) The integrated COP was 92 to 95% of the steady state value at the end of the 15 minute period and it reached 98% during the period after the compressor was deenergized.

CYCLING TESTS

The heat pump was run under cycling scenarios composed of off-periods 3-1/2 minutes and greater and on-periods 3 minutes and greater at entering water temperatures of 50, 70, and 90 F. All external conditions except air flowrate were maintained throughout 4 contiguous cycles of the heat pump. Tests were performed under the conventional control mode, where the compressor and fan are turned off simultaneously; and under the modified control mode where the fan is allowed to run after the compressor is turned off to distribute heat still available from the condenser. During the testing under the

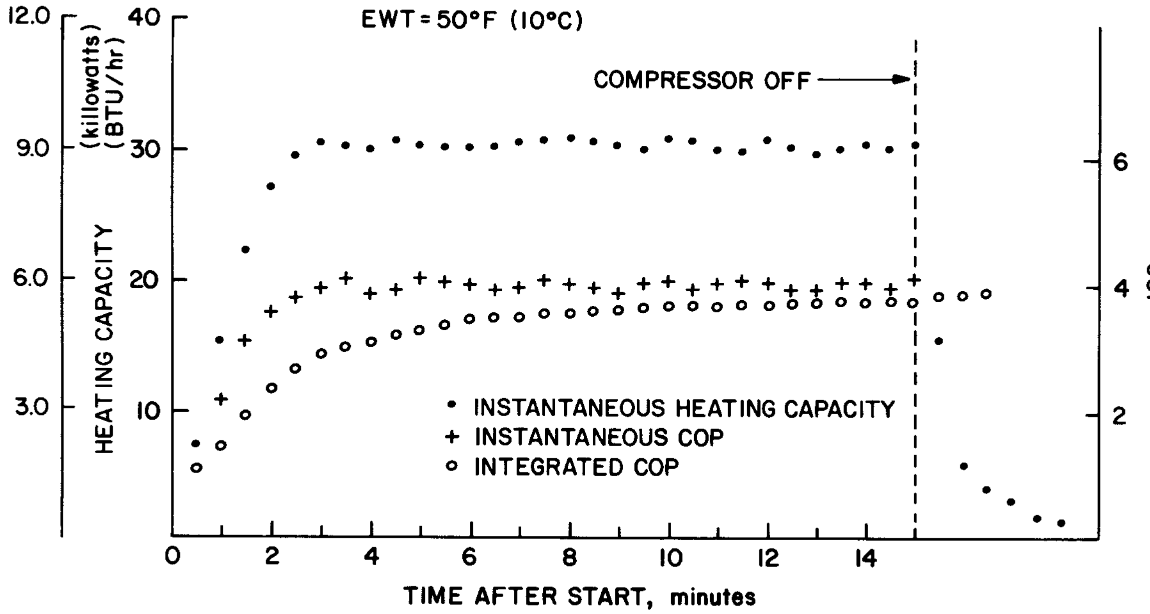

Figure 2. Cold Start Transient Test Data for Northrup SAHP - 50^{O}F Entering Water Temperature.

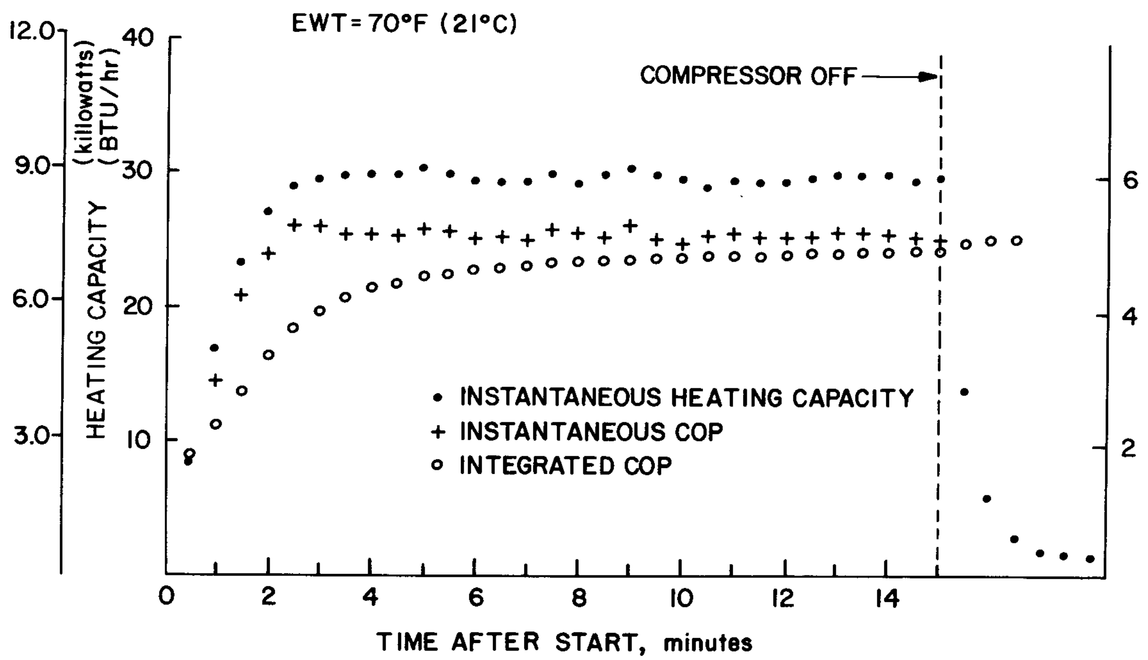

Figure 3. Cold Start Transient Test Data for Northrup SAHP - 70^{O}F Entering Water Temperature.

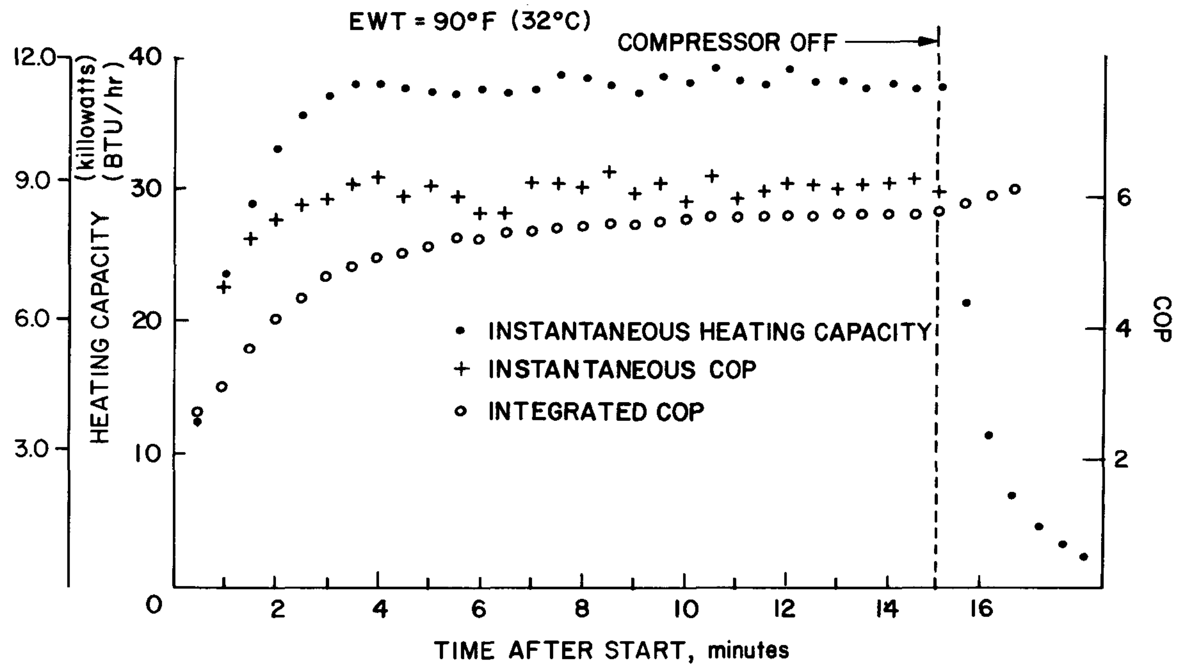

Figure 4. Cold Start Transient Test Data for Northrup SAHP - 90°F Entering Water Temperature.

modified control mode the compressor was shut off and the fan allowed to continue running until the integrated COP began to fall at which time the fan was also turned off. The air flowrate was reestablished within 2.5 seconds of the beginning of each on-period.

Typical data from the cycling tests are shown in Figure 5. The results are summarized in Table 1. Important observations from these data are:

(1) For all cycling scenarios the integrated COP at the end of each cycle; the length of time required to reach steady state; and the steady state COP and heating capacity did not depend on the off-period. Thus the data may be meaningfully represented in the form of Figure 6. Here the ratios of integrated COP and corresponding steady state COP at the end of multiple on-periods are given as functions of duration of on-period for entering water temperatures of 50, 70, and 90 F under the conventional control mode and under the modified control mode. These data are correct only for cycling scenarios consisting of off-periods greater than 3-1/2 minutes.

(2) The maximum integrated COP (or the projected integrated COP for an indefinite number of cycles) was 70 to 80% of the steady state value under the conventional control mode but between 96 and 97% of the steady state value under the modified control mode for the minimum on-period.

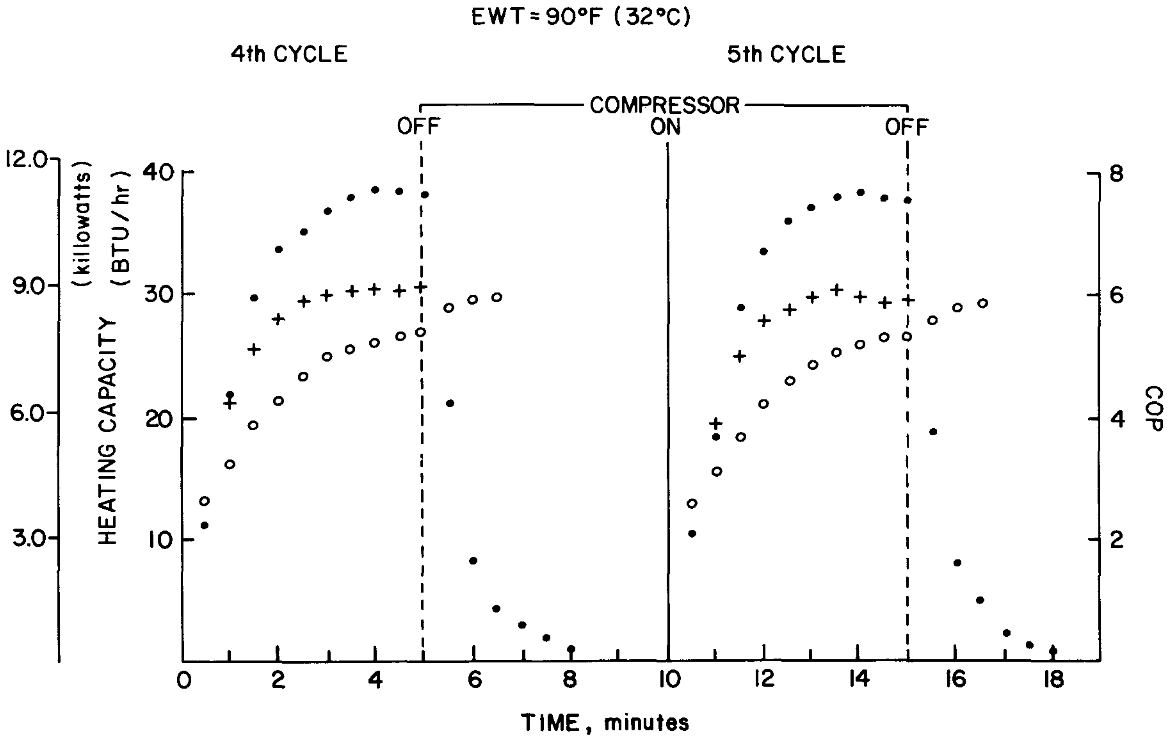

Figure 5. Typical Cycling Test Data for Northrup SAHP.

Table 1. Summary of Cycling Test Data

		Integrated COP at end of cycle								
		Conventional control mode			Modified control mode			Corresponding steady state COP		
On-time	Off-time	90	70	50	90	70	50	90	70	50
3	3.5	4.6	3.5	2.6	5.5	4.7	3.4	5.8	4.9	3.5
5	3.5	5.1	4.0	3.0	5.6	4.8	3.4	5.8	4.9	3.5
12	3.5	5.5	4.5	3.3	5.7	4.8	3.4	5.8	4.9	3.5
3	5	4.6	3.5	2.7	5.5	4.7	3.4	5.8	4.9	3.5
12	5	5.5	4.5	3.3	5.7	4.8	3.4	5.8	4.9	3.5
3	12	4.6	3.5	2.7	5.5	4.7	3.4	5.8	4.9	3.5
12	12	5.5	4.5	3.3	5.7	4.8	3.4	5.8	4.9	3.5

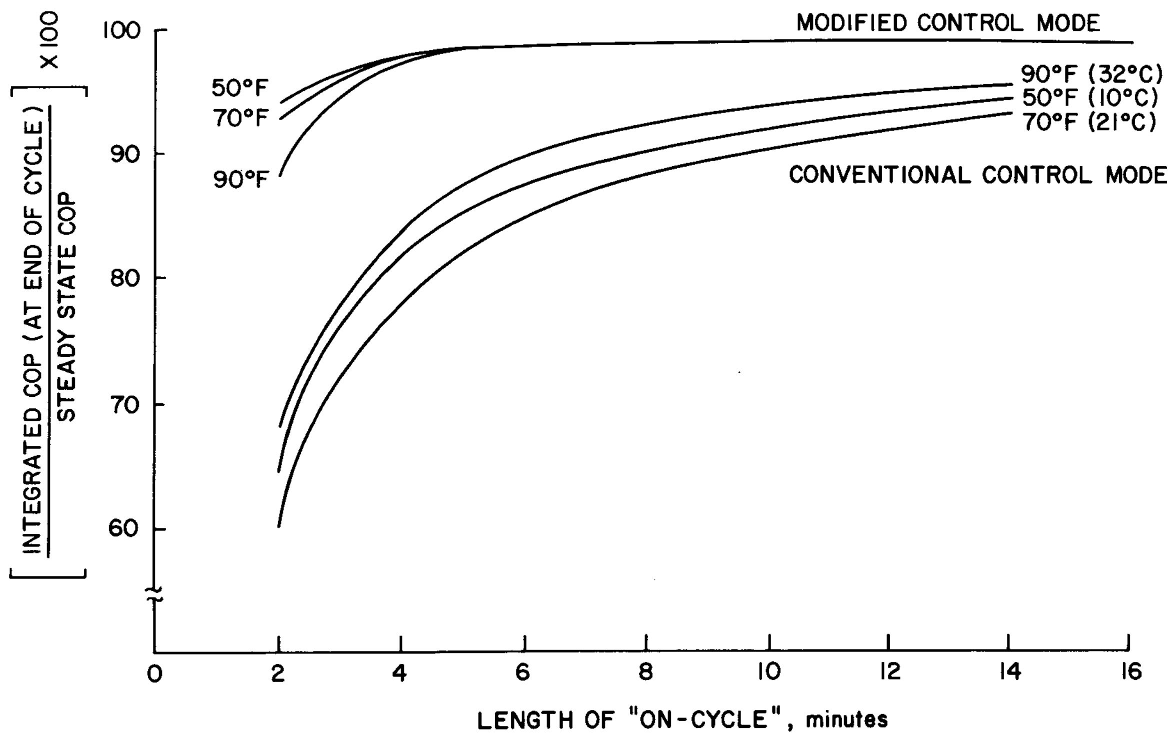

Figure 6. Ratio of Integrated COP to Steady State vs. Duration of On-Period, Entering Water Temperature and Control Mode.

(3) The maximum ratio of integrated COP to the corresponding steady state COP under the conventional control mode ranged between 75% and 95% for on-periods between 3 minutes and 15 minutes.

(4) The maximum ratio of integrated COP to corresponding steady state COP under the modified control mode for all on-periods greater than 3 minutes is nearly constant, ranging from 96% to 98%.

No consideration was given for any heat passively given off by the heat pump to the surrounding space during off-periods under the conventional control mode. Thus the results reported under the conventional control mode represent a minimum possibility.

The results of this study show that the wide capacity/load mismatch associated with high source temperatures may not be a serious problem and the high COPs possible with high source temperatures may be achieved if cycling losses are not severe. The control mode used in this study is a simple and inexpensive one to implement. Similar results have been obtained for absorption chillers by others using this scheme.[4,5]

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