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DEVELOPMENT OF HARDWARE SIMULATORS FOR TESTS OF SOLAR COOLING/HEATING SUBSYSTEMS AND SYSTEMS

PHASE II. UNSTEADY STATE HARDWARE SIMULATION OF RESIDENTIAL ABSORPTION CHILLER

PAUL C. AUH

September 1979

MASTER

Work Sponsored by the
SYSTEMS DEVELOPMENT DIVISION
SOLAR APPLICATIONS
OFFICE OF ASSISTANT SECRETARY
CONSERVATION AND SOLAR APPLICATIONS
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ABSTRACT

Phase II of BNL's Solar Cooling R&D Project, Development of Hardware Simulators for Tests of Solar Cooling/Heating Subsystems and Systems, is reported here. The main work involves the experimental study to determine transient and cycling performance characteristics of an advanced solar absorption chiller.

Laboratory tests of the second generation Arkla chiller (Solaire 36, model WF36), using the BNL simulator, have been performed. The control scheme of the chiller was originally designed such that the capacity drops to zero instantly after shutoff. The simple and effective improvement in chiller performance may involve minor modification in the control strategy so that the maximum cooling potential of the chiller can be realized. Under the transient tests, a control modification was so adopted that the additional cooling capacity during the shutoff transient period could be obtained and utilized.

The results of the shutoff transient performance tests revealed that, during the 10 minutes following the shutoff from steady state, there was significant residual cooling, corresponding to about 4 minutes of running at steady state capacity.

Chiller performance has also been measured against fast and slow cycling periods under both the conventional and modified control modes. Cycling tests under the modified mode have produced results significantly different from those under the conventional control mode, i.e., complete shutoff. The results of the various combinations of on/off cycling runs showed that the net capacity loss during the start-up transient period could be significantly reduced when the residual cooling capacity generated during the off-period is used to compensate for the initial loss. Furthermore, the experimental investigation showed that the performance degradation, due to inherent transient behavior of a chiller, could be significantly improved by the simple control modification.

The degree of performance improvement under the modified control mode, as a function of the cycle period and such effects on the integrated chiller performance, have been thoroughly investigated. Under the modified control mode the need for a large cold-side storage may no longer exist. This may offer significant economical advantages, especially for small residential cooling systems, without sacrifice in their performance.

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INTRODUCTION

Since Brookhaven National Laboratory initiated new solar activities in 1976, various in-house solar research and development projects have been conducted by the Solar Technology Group. These research and development activities are in parallel with the other half of the solar program, i.e., providing technical support to the U.S. Department of Energy.

One of the major in-house R&D projects, in the solar cooling area, has been the development of hardware simulators for tests of solar cooling/heating subsystems and systems. It became apparent that hardware simulators were needed to determine the performance characteristics of new solar cooling devices under both steady state and transient conditions in order to ensure optimum design of the large number of advanced solar cooling/heating subsystems and systems expected to be developed within a few years under several DOE contracts.

The main objectives of the overall solar cooling program are to: (1) develop a hardware simulator, which can be used to simulate any advanced solar cooling/heating subsystem and/or system of residential size; (2) determine steady state & unsteady state performance characteristics and parasitic power requirements of advanced solar cooling/heating subsystems and/or systems; (3) provide base performance data for the validation of computer simulation models for subsystems and/or systems; and (4) optimize system performance based on system configurations, subsystem options, control strategy, and parasitic power requirements.

In order to accomplish the above stated objectives, the proposed work has been divided into the following phases:

Phase I - Development of Subsystem Hardware Simulator of Residential Size, and Steady State Simulation of Most Advanced Solar Cooling Device

Phase II - Unsteady State or Transient Simulation of Same Cooling Device

Phase III - Development of System Hardware Simulator of Residential Size
- Expanded Version of Existing Subsystem Hardware Simulator

Phase IV - Steady State and Transient Simulation of Most Advanced Solar Cooling System of Residential Size

Although the present work has been confined to the simulator of residential size, a commercial-size simulator is also considered to be of great importance since new solar cooling devices of such sizes would be economically more favorable. A separate BNL proposal to build a commercial-size hardware simulator has been presented to DOE (U.S.).

CHAPTERS

1. Phase II Objectives

The main objectives of Phase II work are to:

1. determine the transient and cycling performance characteristics of an advanced solar absorption chiller,
2. conduct a rigorous experimental investigation on the performance degradation of an absorption-type chiller due to its inherent transient behavior,
3. obtain simple and economical solutions to the above problem, and
4. provide actual performance data for the validation of computer simulation models of the solar cooling device (subsystem) and/or the system.

2. Summary of Experimental Results

To accurately predict the performance of a cooling device during a certain period of time under actual weather and load conditions, the performance data of the device under both steady state and transient conditions are necessary. In addition, the performance data will provide useful information for the optimization of an integrated chiller system based on system configurations, subsystem options, control strategy, and parasitic power requirements.

Laboratory studies of the second generation Arkla chiller (Solaire 36, model WF36, E800001) with the BNL simulator have revealed a potential for the performance enhancement by simple modification of the control scheme. The Solaire 36 chiller, while under an extensive performance test program, has been operated under various steady state and transient conditions to determine the limits of performance. Such performance limitations were evaluated relative to the potential corrective measures which may improve the operating efficiency and, consequently, upgrade the system cost effectiveness.

2.1 BNL-Built Hardware Simulator. As a technical monitor of the U.S. Department of Energy (DOE) solar cooling R&D contracts, Brookhaven National Laboratory (BNL) has built a thermally activated hardware simulator to make independent tests of advanced subsystems which will be developed by contractors within the near term.

Figures 2.1 and 2.2 are photographs of the BNL Hardware Simulator Facility. As depicted, the residential-size BNL simulator has two controlled heat sources and one controlled heat sink. Shown in Figure 2.1, from the right-hand side, are the minicomputer data input terminal, data logger, Arkla Solaire 36 chiller, and a portion of the hardware simulator. Instantaneous

Figure 2.1. BNL's Hardware Simulator Facility for Thermally Activated Cooling Subsystems of Residential Size - (A) Front View

Figure 2.2. BNL's Hardware Simulator Facility for Thermally Activated Cooling Subsystems of Residential Size - (B) Rear View

data collection and reduction under transient tests are possible with the data logger connected to the computer by an interface. The details of the simulator have been described in the Phase I report.⁵

2.2 Cold-Start Transient Performance. In order to investigate the start-up transient performance of the chiller at cold-start conditions, (a) the chiller was left inoperative at room temperature for a sufficient time (usually overnight); (b) the external test conditions were present with the simulator. These were T_{gi} (generator hot water inlet temperature), T_{ci} (condenser cooling water inlet temperature), T_{ei} (evaporator chilled water inlet temperature), W_g (generator hot water flow rate), W_c (condenser cooling water flow rate), and W_e (evaporator chilled water flow rate). The starting times of the cold-start runs were recorded as soon as the pumps for W_g , W_c , and W_e were activated.

In Figure 2.3, the test results of a cold-start run are exemplified. The chiller capacity and chiller coefficient of performance (COP) are shown as a function of time, including both the transient cold-start and the following steady state periods. As seen in the figure, the steady state was reached in about 30 minutes from the cold-start at 70°F. During this period, it is observed that:

- The average tonnage of the chiller was 2.8, compared with the steady state capacity of about 3.7, or the chiller produced 76% of its steady state capacity.

- The average COP of the chiller was 0.56, compared with the steady state COP of 0.70, or it corresponds to 80% of its steady state COP.

At 15 minutes after the cold-start, the instantaneous capacity reached 94% of its steady state value. The average value of the capacity or COP, however, was mostly degraded in the first 15 minutes after the cold-start. During the initial 15-minute period, it is seen that:

- The average tonnage of the chiller was 2.2. When compared with the steady state capacity of 3.7, it was only 58% of its steady state capacity.

- The average COP of the chiller was 0.43, which is 61% of its steady state COP value of 0.7

2.3 Shutoff Transient Performance. The control scheme of the chiller (Arkla Solaire 36) was originally designed such that the capacity drops to zero instantly after the shutoff. Therefore, residual cooling capability cannot be utilized. The simple and effective improvement in chiller

Figure 2.3. Cold-Start Transient Performance; Chiller Capacity (& COP) vs. Time

BNL TEST DATA 9/14/78
 ARKLA SOLAIRE 36 CHILLER (SERIAL NO. 800001)
 $T_{gi}/T_{ci}/T_{eo}$ (NOMINAL)=195/85/40°F
 $W_g/W_c/W_e$ (NOMINAL)=11/12/7.1 gpm

BNL TEST DATA 9/15/78
 ARKLA SOLAIRE 36 CHILLER (SERIAL NO. 800001)
 $T_{gi}/T_{ci}/T_{eo}$ (NOMINAL)=190/85/40°F
 $W_g/W_c/W_e$ (NOMINAL)=11/12/7.1 gpm

Figure 2.4. Shut-off (Generator Only) Transient Performance; Chiller Capacity vs. Time

performance may involve minor modification in the control strategy such that the maximum cooling potential of the chiller can be realized. Under the transient tests, a control modification was adopted such that the condensing water pump and chilled water pump could run continuously after the hot water supply to the generator component was cut off. Thus, additional cooling capacity during the shutoff transient period could be obtained and utilized.

Figures 2.4A and B show the results of the shutoff transient performance tests under the new control scheme. In both figures, the chiller capacity is plotted as a function of time during the shutoff period: before this the steady state condition continued for a significant length of time (i.e., several hours).

From Figure 2.4A, the following facts were observed.

- In about 10 to 12 minutes after the shutoff, the residual cooling capacity approached zero.
- During the 10 minutes after the shutoff, the average capacity was 0.91 ton, which is 41% of its steady state value.
- The residual cooling capacity obtained during the 10 minutes after the shutoff corresponded to about 4 minutes of running at its steady state capacity.

Figure 2.4B shows the results of an additional run at lower T_{gi} . Again, very similar results were obtained as follows.

- In about 10 to 12 minutes after shutoff, the residual cooling capacity approached zero.
- During the initial 10 minutes of the shutoff period the average tonnage was 0.80, which corresponds to 39% of its steady state value.
- The residual cooling capacity obtained during the initial 10 minutes of the shutoff period corresponds to about 4 minutes of running at its steady state capacity.

2.4 Cycling Transient Performance. Chiller performance has been measured against fast and slow cycling periods under both the conventional and modified control modes. Cycling tests under the modified mode have produced results significantly different from those under the conventional control mode, i.e., complete shutoff. The degree of performance improvement as a function of the cycle period and such effects on the integrated chiller performance have been thoroughly investigated. All tests have been performed from the cold-start and run for at least several hours.

The following definitions will apply throughout the text:

$$\text{Average Capacity} = \int_0^\theta \dot{Q}_{EVA} d\theta / \int_0^\theta d\theta, \text{ and} \quad (1)$$

$$\text{Integrated COP} = \int_0^\theta \dot{Q}_{EVA} d\theta / \int_0^\theta \dot{Q}_{GEN} d\theta, \quad (2)$$

where

$\dot{Q}_{EVA}$ = instantaneous capacity.

$\dot{Q}_{GEN}$ = instantaneous heat input to generator.

2.4-1 Cycling Tests Under Modified Control Mode

(a) Long-On/Short-Off Cycle

The test of a 60 minute-on/15-minute-off run under the modified control mode (Run No. 6015B) has been performed and the result is shown in Figure 2.5. Only one complete cycle (out of several cycles that were run) is shown in the figure for the subsequent analysis. The results of Run No. 6015B are also Summarized in Table 2.1

Table 2.1
Summarized Results of Run No. 6015B

	Average capacity (tons)	Percent capacity (a)	Integrated COP	Percent intgr. COP (c)
At the end of start- up-period	1.90	63	0.38	58
At the end of on- period	2.86	95	0.61	94
At the end of entire cycle (b)	2.99	100	0.64	98

(a) Relative to steady state capacity (~ 3.00 tons).

(b) On the basis of on-period only.

(c) Relative to steady state COP (~ 0.65).

From the plot of the chiller capacity versus the cycle time, it is observed that:

- Only 8 minutes were required to reach the steady state compared with 30 minutes from the cold-start.

Figure 2.5. Chiller Capacity & COP in 6015B Run vs. Cycle Time

- During the initial 8 minutes of start-up, the average tonnage of the chiller (1.90 tons) indicated a transient capacity degradation of 63% over its steady state capacity (3.00 tons).

- At the end of the on-period, the average capacity (2.86) corresponded to 95% of steady state capacity.

- Without utilizing the residual cooling capability, the start-up loss was 37% of the steady state capacity during the first 8 minutes. With the simple control modification, the residual cooling capacity generated during the shutoff period can be utilized. When this was used to compensate for the initial start-up loss, the average chiller capacity during the entire cycle (2.99) approached the steady state value, or the net capacity loss during the same period was negligible.

Comparison between the plots of the instantaneous chiller COP and the integrated chiller COP showed that:

- The integrated values are always lower than the instantaneous values during the on-period because of the initial start-up loss. The initial start-up loss was, however, mostly recovered during the off-period by the residual cooling capability of the chiller. It is noted in the figure that the integrated COP approached the steady state COP at the end of the entire cycle.

- At the end of the start-up period (8 minutes) the integrated COP (0.38) showed a 42% degradation over its steady state COP (0.65). At the end of the on-period (61 minutes), the integrated COP (0.61) corresponded to 94% of the steady state COP. At the end of the complete cycle (on-period + off-period or 75 minutes), the integrated COP (0.64) approached close to the steady state COP, which meant that the thermal inefficiency due to the cycling was negligible under the modified control mode.

(b) Short-On/Short-Off Cycle

The test results of the 15-minute-on/15-minute-off run under the modified control mode (Run No. 1515B) have been obtained. In Figure 2.6 the plots of the chiller capacity and COP as a function of time are shown for the 6th and 7th cycles of the test run.

The following observations were made from the figure during the 6th cycle.

- The average capacity of the chiller during the on-period (2.54 tons) corresponded to 83% of its steady state capacity (3.06).

Figure 2.6. Chiller Capacity & COP in 1515B Run vs. Cycle Time

- When the total amount of cooling capacity produced during both on and off periods was averaged on the basis of on-period only (i.e., during the solar heat input period), the average capacity (3.13 tons) came close (102%) to steady state capacity. In other words, there was no net cycling loss for this particular run.

- At the end of the on-period, the integrated COP (0.53) was 20% lower than the steady state COP (0.66) because of the start-up loss. This COP loss was recovered completely (100%) at the end of the entire cycle by the residual cooling capacity as seen in the figure.

An analysis of Figure 2.6 is also summarized in Table 2.2

Table 2.2
Summarized Results of Run No. 1515B

	Average capacity (tons)	Percent capacity(a)	Integrated COP	Percent intgr. COP(c)
At the end of on-period	2.54	83	0.53	80
At the end of entire cycle (b)	3.13	102	0.66	100
At the end of on-period	2.36	77	0.48	73
At the end of entire cycle (b)	3.00	98	0.62	94

(a) Relative to steady state capacity (~ 3.06 tons).

(b) On the basis of on-period only.

(c) Relative to steady state COP (~ 0.66).

Very similar results have been obtained from the 7th cycle and they are also shown in the Table. Because of the slower recovery of the capacity at the beginning of the 7th cycle, the start-up loss was not completely recovered at the end of the cycle. However, the loss was small (6%).

(c) Short-On/Long-Off Cycle

Cycling tests for a 15-minute-on/60-minute-off run were performed. On-time of 15 minutes has been selected since it represents a minimum value in order for the chiller to operate under nearly steady state conditions.

Figure 2.7 is a representation of the results on Run No. 1560B. The analysis of the third cycle of the run is tabulated in Table 2.3.

Table 2.3
Summarized Results of Run No. 1560B (3rd cycle)

	Average capacity (tons)	Percent capacity(a)	Integrated COP	Percent intgr. COP(c)
At the end of on-period	2.20	78	0.49	72
At the end of entire cycle (b)	2.82	100	0.63	93
(a) Relative to steady state capacity (~ 2.82 tons).				
(b) On the basis of on-period only.				
(c) Relative to steady state COP (~ 0.68).				

The results of the third cycle are summarized as follows:

- Although the chiller was on for a short time (15 minutes) and off for a long time (60 minutes), the time needed for the start-up-period (6 to 8 minutes) was reasonably short.
- The average capacity during the on-period (2.20) was increased by 28% (2.82) when the residual cooling during the off-period was utilized. This indicates the complete recovery of the start-up loss of the cycle.
- Because of the start-up loss, the integrated COP at the end of the on-period (0.49) was lower than the steady state COP (0.68) by 28%. At the end of the entire cycle, however, the integrated COP (0.63) was well within 97% of the steady state COP. Again no significant loss of the chiller performance resulted under the modified control mode.
- Similar trends were observed for the fourth cycle as seen in Figure 2.7.

(d) Long-On/Long-Off Cycle

The cycle consisted of on-and-off periods of 60 minutes each.

Figure 2.8 shows the second cycle and the start of the third cycle. The results of the second cycle are also summarized in Table 2.4

Figure 2.7. Chiller Capacity & COP in 1560B Run vs. Cycle Time

Figure 2.8. Chiller Capacity & COP in 6060B Run vs. Cycle Time

Table 2.4
Summarized Results of Run No. 6060B (2nd cycle)

	Average capacity (tons)	Percent capacity ^(a)	Integrated COP	Percent intgr. COP ^(c)
At the end of on-period	2.65	93	0.62	91
At the end of entire cycle (b)	2.82	99	0.65	96

(a) Relative to steady state capacity (~ 2.85 tons);

(b) On the basis of on-period only.

(c) Relative to steady state COP (~ 0.68).

Brief comments on the second cycle are made as follows:

- The decrease in capacity due to the start-up loss was recovered within 99% of the residual cooling capacity generated during the off-period.
- The integrated COP (0.62) at the end of the on-period was 9% lower than the steady state COP (0.68). In other words, the start-up loss for the long-on cycle is relatively small compared with that of the short-on cycle even if it is not compensated for by the residual cooling generated during the off-period.
- At the end of the entire cycle, the integrated COP (0.65) closely approached the steady state COP, and very little loss in chiller performance resulted under the cycling conditions with the modified control mode.

Similar trends are expected for the third cycle as partly seen in Figure 2.8.

2.4-2 Cycling Tests Under Conventional Control Mode. To compare the test results under the modified control mode and under the conventional control mode, an analysis of some selected experimental runs under the conventional control mode was made. Two of the data for the simulation of the cycling conditions under the conventional control mode have been reduced and the results are discussed here. Under the conventional control mode, all three pumps (generator water pump, condenser water pump, and chilled water pump) and the chiller itself are completely shut off after each on-period.

(a) Long-On/Short-Off Cycle

The test results of the 60-minute-on/15-minute-off run (Run No. 6015A) are shown in Figure 2.9. Here the residual cooling capability was no longer utilized. It is observed in the figure that:

- During the 8-minutes start-up period, there was a substantial performance loss. At the end of 8 minutes, the average capacity (1.44 tons) was 50% lower than the steady state capacity (2.90 tons), and the integrated COP (0.35) was only 56% of the steady state COP (0.63).

- At the end of the on-period (60 minutes), the average capacity (2.70 tons) approached the steady state capacity (2.90 tons) within 93%. The integrated COP (0.59) corresponded to 94% of the steady state COP (0.63).

A comparison of the results between Runs 6015A (under conventional control mode) and 6015B (under modified control mode) is shown in Table 2.5

Table 2.5
Performance Comparison Between Runs 6015A and 6015B.

	At the end of 8 minutes		At the end of on-period	
	6015A 3rd Cycle	6015B 3rd Cycle	6015A 3rd Cycle	6015B 3rd Cycle
a Steady state capacity (tons)	2.90	3.00	2.90	3.00
b Average capacity (tons)	1.44	1.90	2.70*	2.86
c Percent capacity, (b/a)(100)	50.	63.	93.	95.
d Steady state COP	0.63	0.65	0.63	0.65
e Integrated COP	0.35	0.38	0.59*	0.61
f Percent COP (e/d)(100)	56.	58.	94.	94.

*Extrapolated.

Comparison of the results of Runs 6015A and 6015B shows that:

- The performance degradation during the first 8 minutes in 6015A is slightly higher than in 6015B.

- At the end of on-period, however, the degrees of the performance degradation in both 6015A and 6015B were about the same. Therefore, the benefits derived from the control modification were well justified since the performance enhancement due to the modification was derived from the same base.

Figure 2.9. Chiller Capacity & COP in 6015A Run vs. Cycle Time

(b) Short-On/Short-Off Cycle

For the comparison of shorter cycles, the 15-minute-on/15-minute-off run (Run No. 1515A) was performed and the results were compared with Run No. 1515B. The results of the fourth and fifth cycles of Run No. 1515A are shown in Figure 2.10. The results of Run No. 1515A (fifty cycle) are compared with those of Run No. 1515B (sixth cycle) in Table 2.6.

Table 2.6
Performance Comparison Between Runs 1515A and 1515B.

At the end of on-period	1515A 5th Cycle	1515B 6th Cycle
a Steady state capacity (tons)	2.94	3.06
b Average capacity (tons)	2.30*	2.54
c Percent capacity, (b/a)(100)	78.	83.
d Steady state COP	0.62	0.66
e Integrated COP	0.49*	0.53
f Percent COP, (e/d)(100)	79.	80.

*Extrapolated.

From Figure 2.10 and Table 2.6, it may be said that the degree of performance degradation due to the start-up loss is about the same at the end of the on-period in both cases; therefore, the residual cooling capacity generated during the off-period (under the modified control mode) adds to the enhancement of the chiller performance.

2.5 Performance Enhancement Under Modified Control Mode. Tables 2.7 and 2.8 are presented for the comparison of the chiller performance under the conventional control mode and under the modified control mode. The performance results of some selected runs (all analyzed previously) are shown and the tabulated values were normalized against "B". Here, the "B" values refer to those under the conventional control mode, and the "C" values to those under the modified control mode.

From these tables, it is observed that, under the modified control mode:

- The performance improvement is greater in short-on cycles than in long-on cycles as expected.

Figure 2.10. Chiller Capacity & COP in 1515A vs. Cycle Time

Table 2.7
Percent Increase in Chiller Capacity Under Modified Control Mode

Average capacity (normalized against "B")						
Run No. (Cycle No.)	1515B (6th)	1515B (7th)	1560B (3rd)	1560B (4th)	6015B (3rd)	6060B (2nd)
Condition						
A Steady state(a)	120	130	128	123	105	108
B Without residual cooling	100	100	100	100	100	100
C With residual cooling	123	127	128	122	105	106
D % Increase(b)	23	27	28	22	5	6

(a) based on approximate value for the purpose of comparison.

(b) $D = C - B$.

Table 2.8
Percent Increase in Chiller COP Under Modified Control Mode

Integrated COP (normalized against "B")						
Run No. (Cycle No.)	1515B (6th)	1515B (7th)	1560B (3rd)	1560B (4th)	6015B (3rd)	6060B (2nd)
Condition						
A Steady state(a)	125	138	139	131	107	110
B Without residual cooling	100	100	100	100	100	100
C With residual cooling	125	129	129	123	105	105
D % Increase(b)	25	29	29	23	5	5

(a) based on approximate value for the purpose of comparison.

(b) $D = C - B$.

- The performance degradation due to the start-up loss under any cycling conditions (excluding the cycles with less than 15-minute-on periods) can be recovered within about 93%.

- The performance (both the average capacity and the integrated COP) improvements are about 5 to 6% in long-on cycles and about 22 to 29% in short-on cycles.

3. Conclusions

Solar energy, derived from a solar system is very expensive. Therefore, it is desirable to keep the solar system COP as high as possible. Or the performance degradation of a chiller during transient conditions must be minimized without significant increase in system cost. A simple control modification has been proposed as a possible solution, along with the following conclusions.

- The test results of the cold-start transient performance indicate that the time required by the chiller to reach its steady state condition (about 30 minutes) is significant when compared with the required time (about 8 to 10 minutes) once the chiller is warmed up (as in cycling conditions). During the start-up period, the chiller produced only 76% of its steady state capacity, and the average COP was degraded to 80% of its steady state value.
- The results of the analysis indicate that there are no significant differences in chiller performance at the end of on-periods under the two control modes (i.e., the conventional and the modified control modes). In other words, the residual cooling capability after each on-period under the modified control mode could be a real, added contribution to the chiller performance.
- The study revealed that under the simple, modified control mode of the chiller:
 - (a) The amount of the residual cooling produced was significant and corresponded to about 4 minutes of running at its steady state capacity during each shutoff period from the steady state.
 - (b) Most of the transient start-up loss could be recovered.
 - (c) Significant improvements in both the capacity and the COP were resulted. The more frequent the cycling, the greater the performance improvements.

- (d) A cold-side storage of large capacity may no longer be required. A minimum running time of about 15 minutes or greater may be fixed, or perhaps a cold-pot of very small capacity may be adequate, to prevent the system from frequent cycling with less-than-15-minutes "on" time.
- (e) Performance enhancement without a significant increase in chiller cost may be an important contribution especially to small residential solar cooling systems.

4. Further Study

- For the practical application of the proposed control modification to real solar cooling systems, further study is being planned to optimize the modified control mode. It will involve:
 - (a) The optimization of the modified control mode with respect to the parasitic power consumptions, to the limits of allowable chilled water temperature, and to the method of sequential operation of all related pumps, fans, etc. (including cooling tower, fan/coil unit, etc.) via perhaps time-delayed relay switches, and
 - (b) practical application of the optimized modified control to solar cooling systems.
- Other control strategies to prevent frequent cycling under transient conditions will also be investigated. These may include (a) the regulation of the input hot water temperature to the generator, or (b) the adjustment of input water flow rates to the generator, condenser/absorber, and/or evaporator.
- Dynamic hardware simulation of the chiller will be performed. It will involve input temperature changes in generator hot water, condenser/absorber cooling water, and/or evaporator chilled water. The extent of the temperature change rates will be chosen such that the actual weather conditions in the northeastern USA are simulated.
- The performance simulation of the third generation Arkla prototype unit will be conducted under both steady and unsteady state conditions. The third generation unit, which is evaporatively cooled, requires no separate cooling tower and consumes much less (about one-half) parasitic power than does the second generation unit. The simulation of the third generation unit is planned in FY 80.

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4. P.C. Auh, Evaluation of Performance Enhancement of Solar Powered Absorption Chiller with an Improved Control Strategy Using the BNL-built Hardware Simulator, presented at the 1979 Int. Solar Energy Soc. Congr. Atlanta, Georgia, May 28 - June 1, 1979, BNL 26218.
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