LA-UR-78-930

C.1

TITLE: INITIAL OPERATION AND PERFORMANCE OF A RANKINE CHILLER AND AN ABSORPTION CHILLER IN THE NATIONAL SECURITY AND RESOURCES STUDY CENTER

AUTHOR(S): J. C. Hedstrom, H. S. Murray and J. D. Balcomb

SUBMITTED TO: Third Workshop on the Use of Solar Energy for the Cooling of Buildings
February 15-17, 1978, San Francisco, CA

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

INITIAL OPERATION AND PERFORMANCE OF A RANKINE CHILLER AND AN ABSORPTION CHILLER IN THE NATIONAL SECURITY AND RESOURCES STUDY CENTER*

(DOE CONTRACT NO. W-7405-ENG.36, D494)

by

J. C. Hedstrom, H. S. Murray and J. D. Balcomb
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

General The Study Center is a building with 60,000 ft^2 of heated space that houses the laboratory main libraries and provides a study area for visiting personnel. The building is solar heated and cooled with an 8,000 ft^2 array of flat plate collectors facing south in one plane forming the roof of the equipment room. The collectors have a selective surface of black chrome and are single-glazed with water-white glass. A paraffinic oil is used as the collector coolant which transfers heat to water through a heat exchanger. In the cooling mode hot water is stored in a 5,000 gallon pressurized tank and chilled water is stored in a 10,000 gallon tank. Two water chillers are now installed in the equipment room--one a conventional York lithium-bromide absorption unit (ES1A2) derated to 85 tons with 185°F hot water, and the other a Rankine unit designed and fabricated by Barber-Nichols. The design point for the Rankine unit was 77 tons with 200°F hot water.

The solar energy system has been in operation since March 1977. A 40-channel Hewlett Packard data acquisition system was installed on a temporary basis in June 1977 and was operating in August. A PDP 11/34 mini-computer has now been installed and has been operating since December 1977.

System Description A schematic of the solar energy system and the HVAC equipment is shown in Fig. 1. A paraffinic oil is circulated through the collector array and exchanges heat to water in a tube and shell heat exchanger. In the cooling mode hot water is stored in a 5,000 gallon pressurized storage tank. Hot water is pumped to either the Rankine unit or the absorption unit through Valve E and is returned to the bottom of the tank. When the tank temperature is below the set point (∿170°F) water is heated in a steam heat exchanger by closing Valve E and opening Valve H. Steam is provided from a central steam supply system. The chillers provide chilled water to cooling coils in the two air handling units. The coils have face and bypass dampers which modulate the air temperature leaving the air handlers.

When in the solar mode, the 10,000 gallon tank is in series with the chiller and the cooling coils by opening Valves F and L and closing Valve K. Any cooling capacity not utilized by the building is stored in the cold storage tank. The cooling tower rejects the heat from the chiller by pumping water through Valve G. The tower is also used at night to cool the 10,000 gallon cold tank by pumping water through Valve D.

The control sequence has been modified to operate in the following manner. When the fans start at 6:00 a.m., chilled water from the cold tank is provided to the cooling coils if required. Auxiliary operation is not permitted if the cold tank is below a predetermined set point (∿65°F). The chiller starts after the solar system has heated the hot storage tank to 180°F. The chiller continues to operate until either the hot storage tank drops below 170°F or the cold tanks drop below 48°F. This sequence of operation is an attempt to provide maximum performance of the system by 1) running the chiller when the collectors are operating to reduce collector temperatures, 2) forcing maximum chiller operating times and minimizing cycling, 3) operating the chiller at full capacity without internal throttling (particularly important with the Rankine unit) and 4) not allowing auxiliary operation until the cooling effect from the cold tank is exhausted.

The HVAC system has two air handling units, one for the perimeter of the building and one for the interior of the building. The HVAC systems are of the variable air volume type which maintain room temperature by regulating the amount of air into the zone. The temperature of the air is determined by the zone requiring the most cooling. The air handling units have the ability to modulate the amount of fresh air and return air and have washers for evaporative cooling downstream of the cooling coils. This arrangement works well in the dry New Mexico air. As more cooling is done with the coil, the air washer is not as effective. The perimeter air handling unit also has a heat-pipe

*Work performed under the auspices of the U. S. Department of Energy, R&D Branch for Heating and Cooling, Office of the Assistant Secretary for Conservation and Solar Energy.

recovery unit between the fresh air and the return air.* In summer, an air washer saturates the return air which then removes heat from fresh air through the heat recovery unit. This cooling mode is able to pre-cool the fresh air by about 9°F with an ambient air temperature of 85°F.

In summary, the HVAC systems have five modes of cooling which operate in sequence depending on the cooling demand (thermostat pneumatic pressure) of the zone requiring the most cooling.

1) Full fresh air
2) Direct evaporative cooling
3) Heat recovery evaporative cooling (perimeter only)
4) Cooling from cold storage
5) Chiller cooling (solar or auxiliary)

Results A monthly summary obtained for two months of cooling is presented in Table I.

Table I

MEASURED RESULTS
1977
(Collector Area = 7705 ft^2)

		Aug. 10^6 BTU	Sept. 10^6 BTU
Total Incident Solar Energy	=	394.3	413.1
Solar Energy Collected	=	104.4	97.6
Solar Energy to Chiller	=	76.1	59.4
Aux. Energy to Chiller	=	28.2	5.4
Solar Chiller Energy Output	=	43.9	36.5
Aux. Chiller Energy Output	=	10.3	2.0
Collector Efficiency	=	26%	24%
Chiller COP on Solar	=	0.58	0.614
Percent Solar Heat to Chiller	=	73%	92%
Absorption Operating Days		30	2
Rankine Operating Days		1	20

The absorption chiller was operated 30 days during the month of August and two days in September while the Rankine unit was operated one day in August and 20 days in September. The monthly solar COP is defined as the chilled water energy output divided by the solar hot water input. Due to the limited amount of data channels available last summer, the electrical energy to the pumps and chillers was not measured. A total system COP was therefore not obtained for these months but will be measured in 1978 with the new data acquisition system. We feel the performance of both chillers can be improved with proper operation and with the modified control system.

*This unit is also used in winter for heating the fresh air.

The daily energy incident on the collector and the collector output is plotted in Fig. 2 for the two months. On a good solar day the collectors have an output of about 800 BTU/day ft^2 or a daily efficiency of 33%. The monthly efficiency is about 25% as shown in Table I.

The daily energy values for chiller solar hot water input and chilled water output are shown in Fig. 3. The ratio of output to input is the daily COP of the chiller. The absorption unit had poor performance from the 25th to the 27th of August due to salt solution in the evaporator pan.. This occurs when operating with low temperature hot water from the steam heat exchangers. The steam valves on the steam supply were undersized and could not meet the capacity of the absorption chiller. The absorption unit will automatically pump solution into the evaporator pan to prevent the refrigerant pump from running dry. The steam supply problem will be corrected before this summer.

The Rankine unit had poor performance from August 31 to September 10 due to excessive oil in the evaporator. This oil migrated from the oil sump to the evaporator during shipment to Los Alamos. The gear box on the York vapor compression unit was extensively modified by Barber-Nichols and the reason for this oil migration is not well understood. However, the vapor compression unit has an oil return system which should remove most of the oil from the evaporator. After September 10 the Rankine unit ran fairly well, but still below the performance obtained by Barber-Nichols in their tests in Denver. We feel that some excess oil remained in the evaporator during the last part of September.

The data system samples and reduces the data every forty seconds. An online X-Y plotter plotted some of the data each cycle. Instantaneous plots of COP for the Rankine and absorption units are shown in Figs. 4 and 5. The Rankine unit reaches a peak COP in one minute and then decreases as the hot water and chilled water temperatures decrease. The first peak is because the cooling tower has a 1,000 gallon sump which is initially cold.

The absorption unit takes 30 minutes to generate enough refrigerant to handle the cooling capacity and obtain peak performance. Some of the energy expended in reaching this state is regained, however, on shutdown when the unit goes into the dilution cycle and depletes the refrigerant stored in the evaporator pan.

Two more absorption unit runs are shown in Figs. 6 and 7. The unit was operating at part load by bypassing hot water around the generator in Fig. 6. This was because the chilled water outlet temperature was at 45°F. The absorption unit can have good performance at part load; however, on a further load reduction the unit will shut off and on, resulting in poor performance. The run in Fig. 7 shows the chiller cycling on demand from the building which can result in overall poor performance.

The average absorption COP for five lengthy performance runs was 0.668 and the average Rankine COP for nine runs was 0.697 or 4% higher. By eliminating the oil from the Rankine chiller's evaporator and the average daily Rankine COP should increase to about 0.8.

The "steady-state" COP values obtained from both chillers are shown in Fig. 8 as a function of a special plotting parameter called the "Carnot COP." Carnot COP is defined as:

$$\text{Carnot COP} = \frac{T_{hw}-T_{cw}}{T_{hw}} \times \frac{T_{chw}}{T_{cw}-T_{chw}}$$

T_{hw} = Hot water inlet temp., °R

T_{cw} = Condenser water inlet temp., °R

T_{chw} = Chilled water outlet temp., °R

The Rankine unit has a lower COP than the absorption unit at small values of Carnot COP but has a higher COP at more favorable conditions. The absorption unit has a higher capacity which pulls the solar system down to a lower operating temperature (∿175°F) resulting in more operation below a Carnot COP of 3, whereas the Rankine unit can stabilize with a collector outlet temperature of about 185°F. With lower capacity, the cooling tower also runs slightly cooler which results in the Rankine unit running at a Carnot COP between 3 and 4.

These results were replotted in Fig. 9 as the ratio of the observed to the ideal COP as a function of Carnot COP. A linear fit in these coordinates implies that the actual COP is a quadradic function of Carnot COP. Also plotted on this graph are the results obtained by Barber-Nichols.

Our results are about 15% lower than Barber-Nichols results, which we attribute, at this time, to oil in the evaporator. If there were no capacity changes in either machine, one would expect a pure thermodynamic behavior or a zero slope to these curves.

The steady state capacity of both machines is plotted in Fig. 10 as a function of inlet hot water temperature. Both units slightly exceed their rated design point. Because the absorption unit has a higher capacity it stabilizes with the solar collectors at 175°F, whereas the Rankine unit will equilibrate at 185°F.

The Rankine unit in this system will then generally operate at a higher temperature, therefore, better performance, since it is better load-matched to the collector output.

In October we removed the oil from the Rankine evaporator by removing and distilling the R11 refrigerant. The full PDP-11 data system is now operating and monitoring all 180 channels of instrumentation including electrical energy consumption of all pumps and fans. Temperature instrumentation has been modified for greater stability and accuracy. Hopefully, all operational problems have been corrected, and testing and evaluation will be resumed in May 1978.

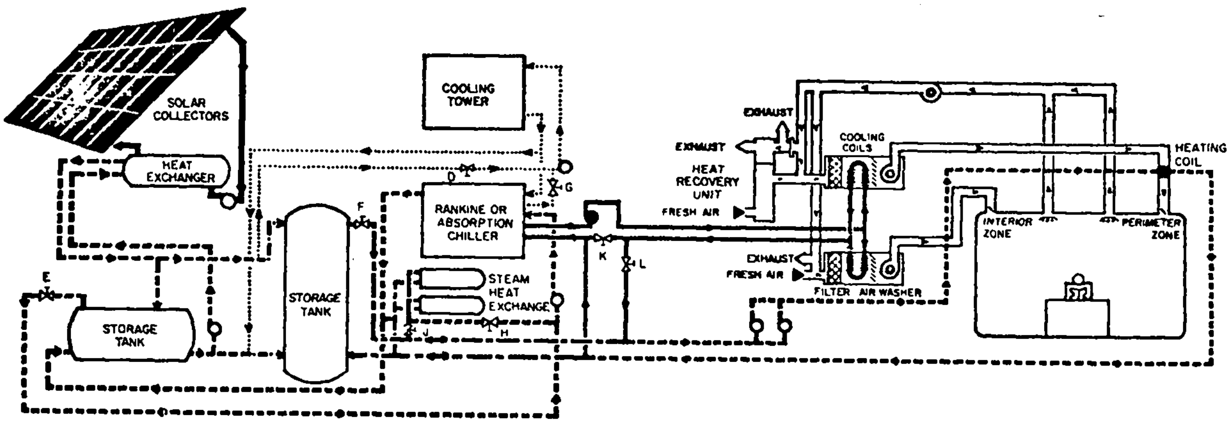

Fig. 1. National Security and Resources Study Center Mechanical System Schematic.

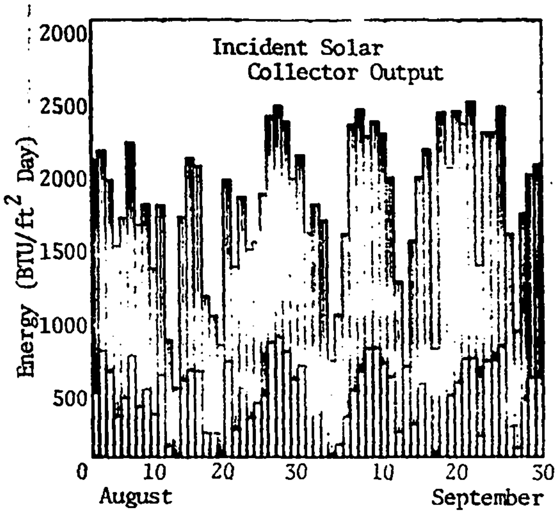

Fig. 2. Daily collector performance

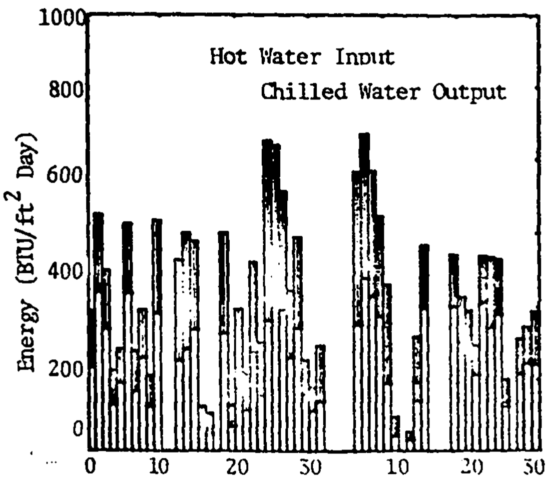

Fig. 3. Daily chiller performance

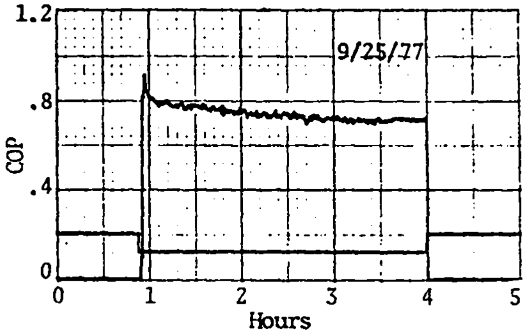

Fig. 4. Instantaneous performance of Rankine unit.

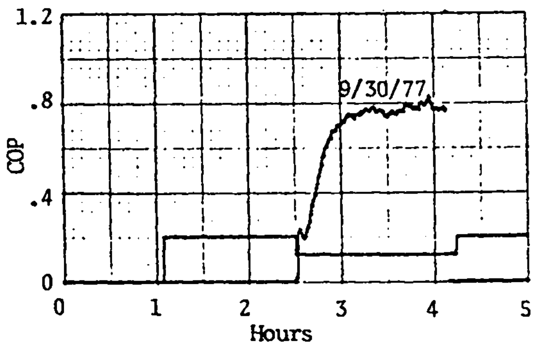

Fig. 5. Instantaneous performance of Absorption unit.

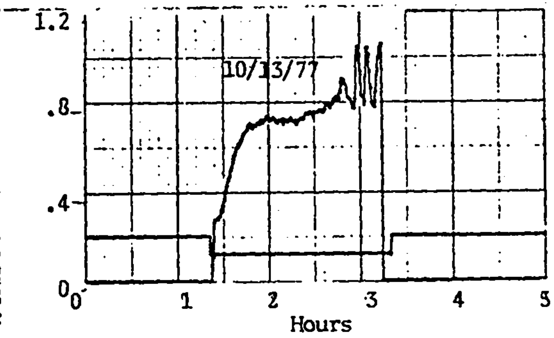

Fig. 6. Instantaneous performance of absorption unit under part load conditions.

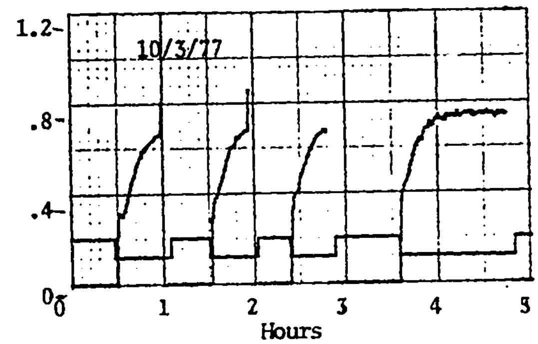

Fig. 7. Instantaneous performance of absorption unit under cycling conditions.

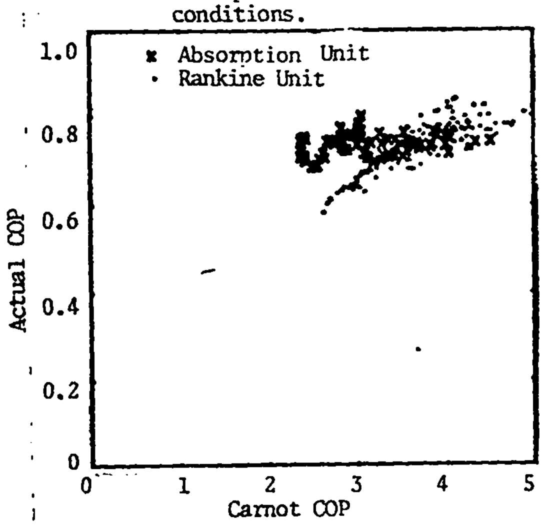

Fig. 8. Steady state coefficient of performance for the Rankine and the absorption chillers.

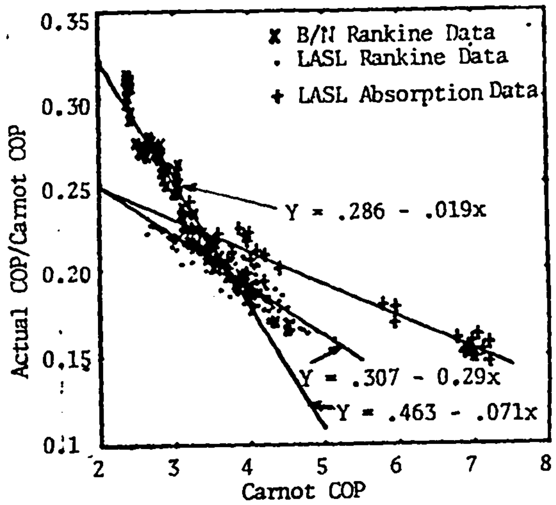

Fig. 9. Least square fits to the Rankine and absorption chiller COP data.

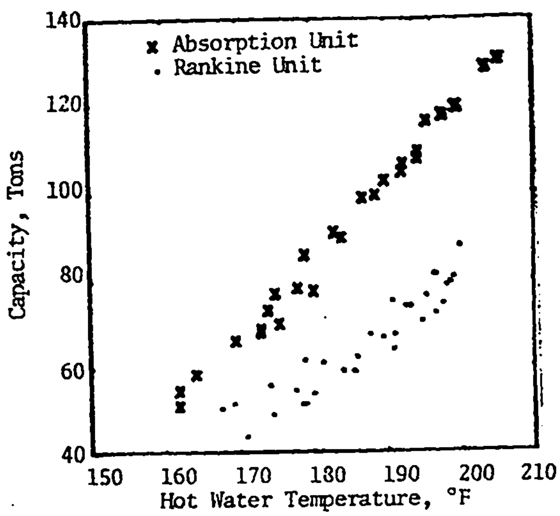

Fig. 10. Measured chiller capacity at steady state conditions