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TITLE: VAPOR-PHASE HEAT-TRANSPORT SYSTEM

AUTHOR(S): James C. Hedstrom

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Washington, D.C.
September 26-28, 1983

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

PROJECT SUMMARY

Project Title:

Passive Thermal Transport by Vapor Phase

Performing Institution:

Los Alamos National Laboratory
MS/K571
Los Alamos, New Mexico 87545

Project Manager:

Robert W. Jones, (505) 667-6441

Project Objectives:

The objectives of this research are to explore the behavior of vapor-transport systems of much larger geometry than present-technology heat pipes and to test a vapor system in a prototype solar building environment so as to uncover engineering obstacles, if any.

Project Status:

A vapor system was constructed in one of the passive test cells at the Los Alamos solar laboratory. Data were obtained on five different configurations beginning in March 1983. Some comparisons of results were obtained with other passive systems in other test cells.

Plans and Objectives for FY 1984:

Continue testing of some of the more promising configurations in the passive test cell over the winter months and compare performance with passive systems in the other test cells. Obtain data suitable for validation of vapor-transport system computer models. Design, construct, and operate bench-scale experiments as necessary to evaluate concepts. Start design of a full-scale vapor system on existing solar building.

Major Publications Related to Project:

D. A. Neeper and R. D. McFarland, "Some Potential Benefits of Fundamental Research for the Passive Solar Heating and Cooling of Buildings," Los Alamos National Laboratory report LA-9425-MS (August 1982).

Contract Number:

W-7405-ENG-36

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Albuquerque Operations Regional Office

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$100K

VAPOR-PHASE HEAT-TRANSPORT SYSTEM*

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ABSTRACT

A vapor-phase heat-transport system is being tested in one of the passive test cells at Los Alamos. The system consists of one selective-surface collector and a condenser inside a water storage tank. The refrigerant, R-11, can be returned to the collector by gravity or with a pump. Results from several operating configurations are presented, together with a comparison with other passive systems. A new self-pumping concept is presented.

INTRODUCTION

Vapor-transport systems can offer performance improvements over current state-of-the-art active and passive solar energy space-heating systems because of higher heat-transfer rates obtained in the evaporation and condensation processes and lower system heat losses at night. We are currently investigating a system consisting of an active-type solar collector with passive water storage. The passive discharge operates at lower temperatures, which also improves performance. Previous system analyses (Neeper, 1982, and Swisher, 1981) have shown improvements of up to 100% over a Trombe wall passive system. Vapor systems should have simpler controls than conventional active systems; we would expect, therefore, improved reliability. The greatest advantage is their promise in low-cost, modular, retrofit applications.

Most of the vapor systems proposed or in operation orient the condenser above the collector, allowing the condensed liquid to return to the collector by gravity. In this configuration, the collector is full of liquid, keeping the vapor from superheating and the absorber from reaching high temperatures. The condenser remains dry, a condition that exposes the maximum area for vapor condensation, thereby minimizing the saturation temperature of the vapor. If it is feasible, this orientation is the best configuration and should yield the highest performance.

In this program, we address situations in which locating the collector below the condenser is not feasible, such as systems with collectors on the south side of a building or on the roof with storage units within the occupied space.

The initial phase of this program has involved constructing a vapor-transport system in one of the 14 passive test cells at the Los Alamos solar laboratory. These cells have been operating for the past 5 years in many passive configurations whose test results were documented (McFarland, May, 1982, and October, 1982). By operating the vapor system alongside other passive systems, we can get a direct comparison of any performance improvement.

DESCRIPTION OF EXPERIMENT

A schematic of the vapor-transport system built into the passive test cell is shown in Fig. 1. One selective-surface, single-glazed collector with a gross area of 24.2 ft^2 with a copper absorber plate and 3/8-in. copper tubes spaced 2 in. on center was mounted on the south wall. The black chrome selective surface has an absorptivity of 0.95 and an emissivity of 0.10. The water tank inside the test cell is 36 in. by 12 in. by 96 in. high, filled to a depth of 78 in. for a total volume of 154 gal. The condenser submerged in the water is a coil of 3/8-in. i.d. copper tubing approximately 16 ft long; the piping connecting the various components on the system is 1/2-in. o.d. hard copper tubing.

The pump, grossly oversized for this particular experiment, is a positive-displacement diaphragm type with a constant flow rate of 2 gpm. We controlled the pump with a float switch in the collector-outlet vapor separator. The check valve used in the initial tests was a 1/2-in. water-type swing check; later, in the self-pumping configuration, we used in-line, 3/8-in. refrigerant, spring-loaded check valves.

All of the test cells have electric heaters that are controlled by the computer-based, data-

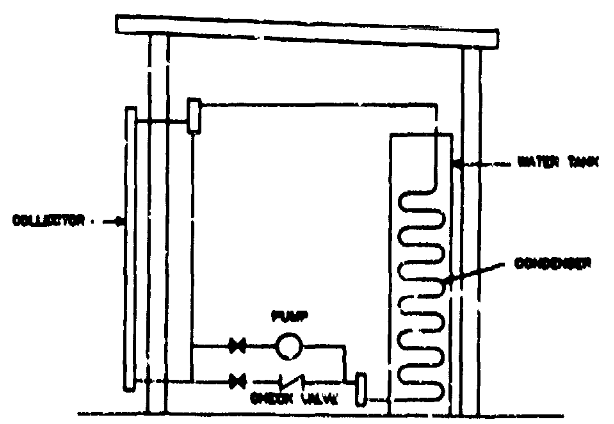

Fig. 1. Schematic of vapor-transport test cell with vertical collector.

*Work performed under the auspices of the US Department of Energy, Office of Solar Heat Technologies.

acquisition system. The room temperature of each cell is scanned every 30 seconds, and when the temperature drops below the set point, the heater is turned on. The cells have a controlled infiltration four air changes per hour.

EXPERIMENTAL RESULTS

Construction of the vapor-transport test cell was completed in March 1983. Since then, we have obtained data in periods of several days to several weeks with the test cell in various operating configurations. Listed below are the basic configurations we have tested:

1. Vertical collector, gravity liquid return (three refrigerant levels);
2. Vertical collector, pumped liquid return;
3. Tilted collector, gravity liquid return (two refrigerant levels);
4. Tilted collector, pumped liquid return; and
5. Tilted collector, self-pumping liquid return.

Each of the first two configurations was tested with a vertical collector on the south wall of the test cell. Because of the low solar incidence on the vertical surface, on May 17 we tilted the collector 35° from horizontal.

The first configuration is shown in Fig. 1, with the condensed liquid returning to the collector by gravity through the check valve. We found that the liquid would percolate in the collector, keeping the tube surfaces wet. We observed in a sight glass on the collector outlet that liquid would spill over the top (about 100 in. above the test-cell floor) about every 30 seconds. We changed the amount of R-11 in the system several times during this configuration to obtain the optimal liquid level, that is, the level at which we expose as much condenser area to vapor as possible while still having liquid percolate to the top of the collector. We found this level in the condenser to be about 40 in. above the test-cell floor.

A plot of several temperatures in the test cell is shown in Fig. 2 with the optimal liquid level. The collector-outlet temperature and the storage-inlet temperature stay relatively close, which means that little superheating is taking place in the collector. The average daily swing in the storage temperature is 7°F. During this time, we maintained the test-cell setpoint of 65°F by auxiliary heating.

The other configuration for operating the system calls for returning the liquid to the collector with a pump. This mode guarantees that, if we fill the system properly, the collector is full and the condenser is dry. The pump was controlled by a float switch in the vapor separator on the collector outlet; whenever the liquid level would drop in the separator, the pump would turn on. Typically, the pump would run about 1 second every minute. It would have been better to put a sump at the pump inlet and to run the pump when the sump was full so that the pump would not run continually in the event of a leak. This modification is being made to the test cell.

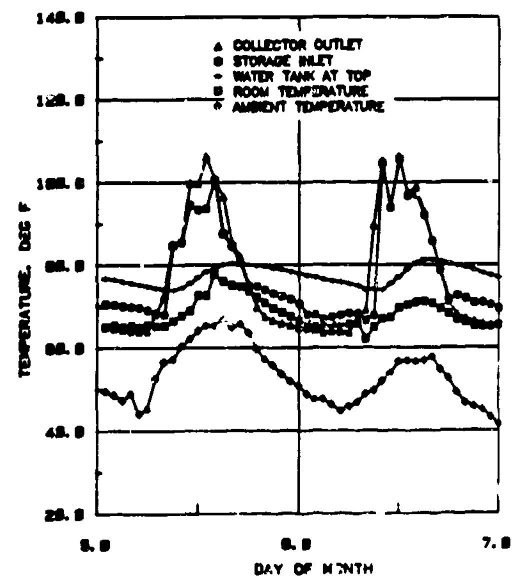

Fig. 2. Temperatures obtained from vapor-transport test cell on May 5-6, 1983. Collector is vertical and liquid is percolating to the top of the collector. Liquid level is 42 in. in the condenser.

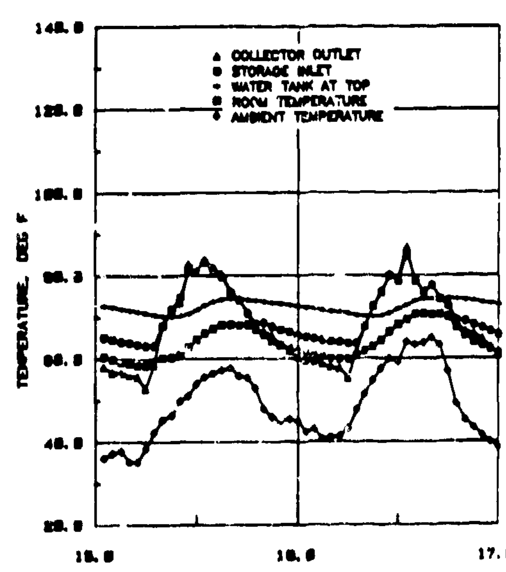

Fig. 3. Temperatures obtained from vapor-transport test cell on May 15-16, 1983. Collector is vertical. The pump is returning the liquid back to the collector.

A 2-day temperature plot with the system in this mode (No. 2 above) is shown in Fig. 3. Temperature swings at the top of storage are reduced to 4.5°F because of the greater volume of usable storage. The collector-outlet temperature is also lowered because of the larger condenser area, and no superheating at all is occurring in the collector. Unfortunately, the auxiliary controller was not working during this period and the room temperature dropped below 65°F.

The next data were obtained with the collector tilted so that we could collect more solar energy during the summer. The tilted-collector configuration is shown in Fig. 4. At this time we removed the glass cover from the collector, installed thermocouples on the absorber tubes, and installed a pressure transducer in the vapor line. We found that with the collector tilted, the liquid would not percolate in the collector. Apparently the vapor can rise at the upper side of the tube without pushing the liquid along with it.

We first ran the system with the collector partially full of liquid; temperature plots in this mode are shown in Fig. 5. The absorber temperature at the collector exit increased to 250°F. The saturation temperature is determined from the pressure-transducer output and the saturation curve for R-11. The collector-outlet temperature is not plotted but is superheated about 30°F.

We then added enough R-11 to the system so that when the collector was hot, it would be exactly full of liquid. A plot of temperatures in this mode of operation is shown in Fig. 6. Now the absorber temperature and the saturation temperature are within 3°F. The condenser, however, is over half full and the daily temperature swing of the upper storage is 25°F.

We next ran the system with the pump returning the liquid to the collector, which operation drains the condenser and fills the collector. The 2-day plot in Fig. 7 shows the storage swing reduced to 17°F and the temperature difference between saturation and storage to be smaller. A 9-hour plot of all the measurements taken on the absorber surface is shown in Fig. 8. All temperatures are seen to be within 14°F of the saturation temperature, indicating that the boiling heat transfer in the collector is very good.

The performance of the passive test cells has been determined and reported for the winters of

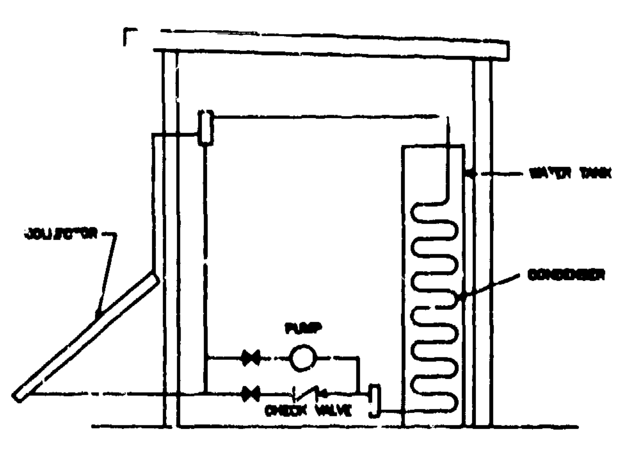

Fig. 4. Schematic of vapor-transport test cell with tilted collector.

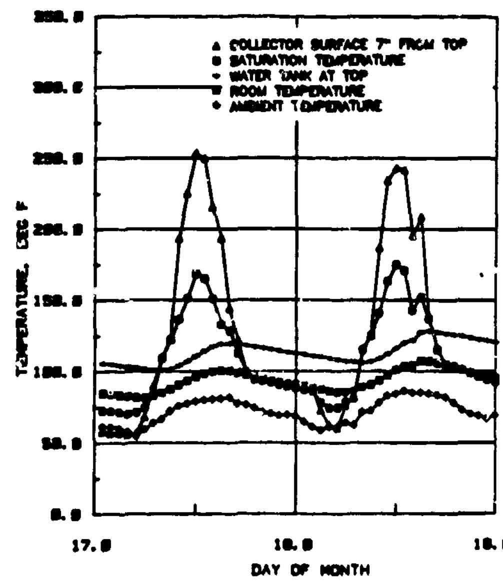

Fig. 5. Temperatures obtained from vapor-transport test cell on June 17-18, 1983. Collector is tilted and liquid is returned by gravity. Liquid level is 35 in. in the condenser. Top of the collector is dry.

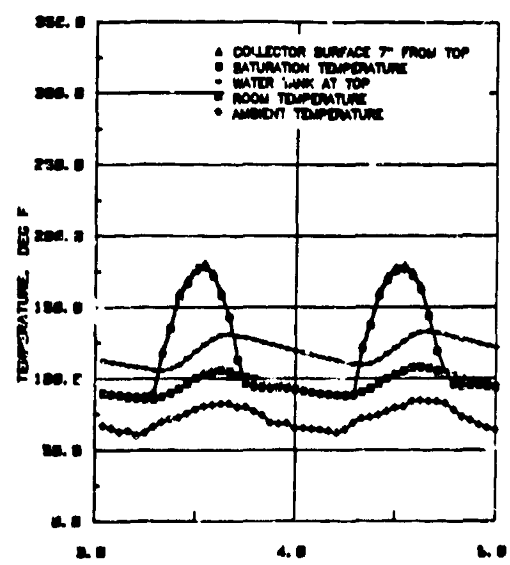

Fig. 6. Temperatures obtained from vapor-transport test cell on July 3-4, 1983. Collector is tilted and liquid is returned by gravity. Liquid level is 56 in. in the condenser. Collector is full of liquid.

1980-81 and 1981-82 by means of analyses of the energy balances in the test cells over time periods of several weeks. The solar energy delivered to each test cell was determined by subtracting the auxiliary energy and any change in stored energy from the test-cell heat loss; the load coefficients for each test cell were determined by nonsolar load calibration tests. The same method

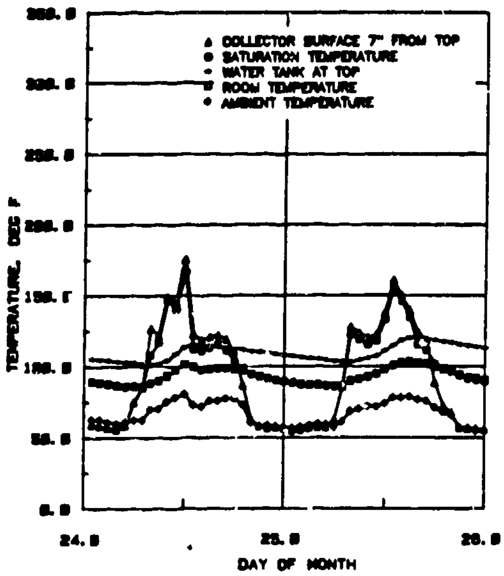

Fig. 7. Temperatures obtained from vapor-transport test cell on July 24-25, 1983. Collector is tilted. The pump is returning the liquid back to the collector.

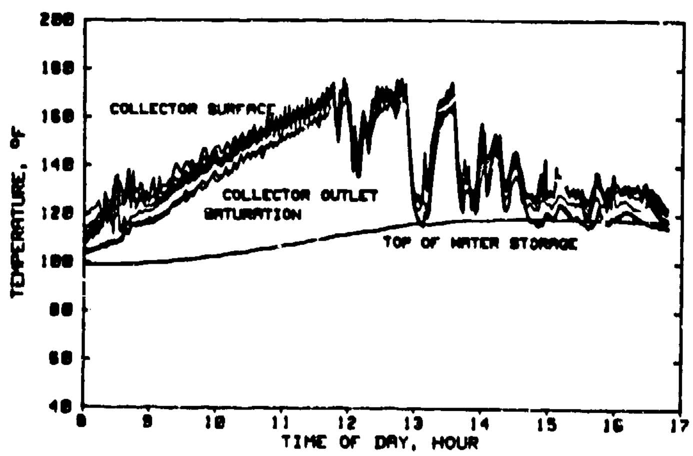

Fig. 8. Seven temperatures on surface of collector, collector-outlet temperature, saturation temperature, and storage temperature on July 28, 1983. Collector is tilted and pump is returning the liquid back to the collector.

was applied to the vapor-transport test cell for the time periods in which we ran the various operating configurations. The results are shown in Fig. 9. To make a rough comparison with previous test-cell results, we plotted the constant efficiency line for the selective-surface water wall (32%) and the flat black Trombe wall (24%). These were the results obtained for February 26-March 22, 1982. The plot shows that the vertical results are comparable to the other passive systems. Sun angles were higher and incident solar radiation was lower for the vapor system. Results for the tilted-configuration tests show higher

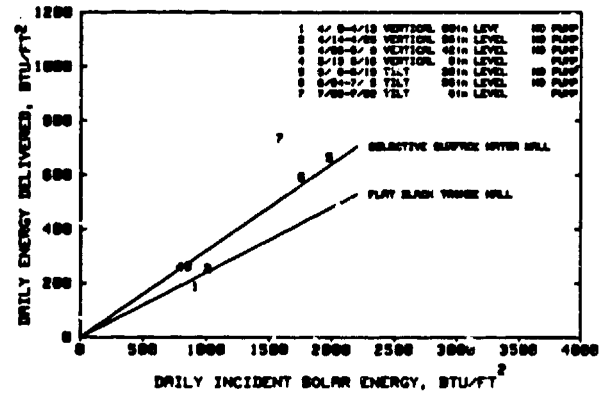

Fig. 9. Daily performance of the vapor system in the various configurations. The results of the passive systems were determined in 1982.

performance in all cases; in particular, the pumped configuration had an efficiency of 46%. We plan to make direct comparisons throughout next winter by tilting the collector back to vertical this fall. The vertical daily solar radiation plotted in Fig. 10 shows that we will obtain solar inputs of 2000 Btu/ft^2-day.

We are currently evaluating a self-pumping configuration as shown in Fig. 11. We have observed that the pressure in the system increases from 10 to 50 psi as the condenser is filled with liquid. The system takes advantage of this phenomenon by pushing liquid through the check valve up into the accumulator as the condenser attempts to increase in liquid level. When such a system was evaluated (Tamburini, 1978), the accumulator would discharge liquid when the boiler started to dry out. We find that without the solenoid, the liquid remains in the accumulator because of the lower saturation temperature and pressure of the accumulator. The collector-liquid level decreases as the difference in saturation conditions increases on each side of the system. To dump the liquid in the accumulator back into the collector, we need to equalize the pressure between the top of the collector and the accumulator. We are in the process of installing an electric float switch in the accumulator to open a solenoid when the accumulator attempts to fill with liquid. To check the validity of such a scheme, we have operated the solenoid manually. The change of temperatures in the system when this valve is cycled is shown in Fig. 12 . The change in collector temperatures as the collector is refilled with liquid is dramatic. However, the condenser contains more liquid on the average, as indicated by the higher saturation temperature. It remains to be seen what the average liquid level in the condenser will be when the solenoid operates over a period of a day. We hope to evaluate this concept with the electric solenoid but will search for some commercial, mechanical, float device, such as a steam trap or an air vent, that will work without electricity.

Many other self-pumping schemes (Wachtell, 1978) have been studied and could be evaluated experimentally in this test cell.

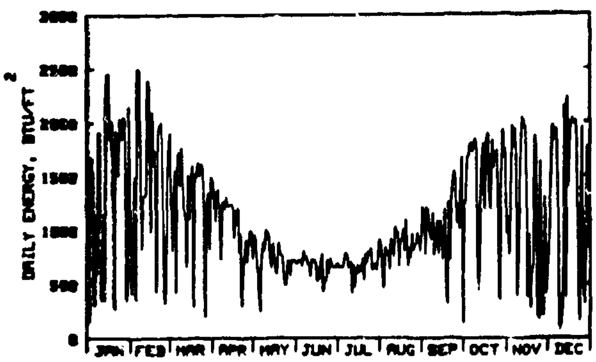

Fig. 10. Daily solar radiation on a vertical surface in Los Alamos in 1982.

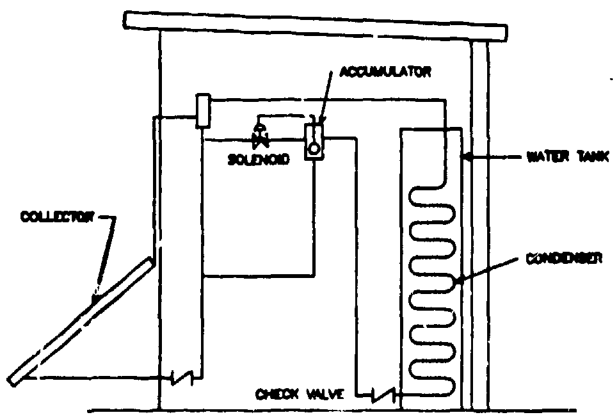

Fig. 11. Schematic of a self-pumping concept for the vapor-transport test cell.

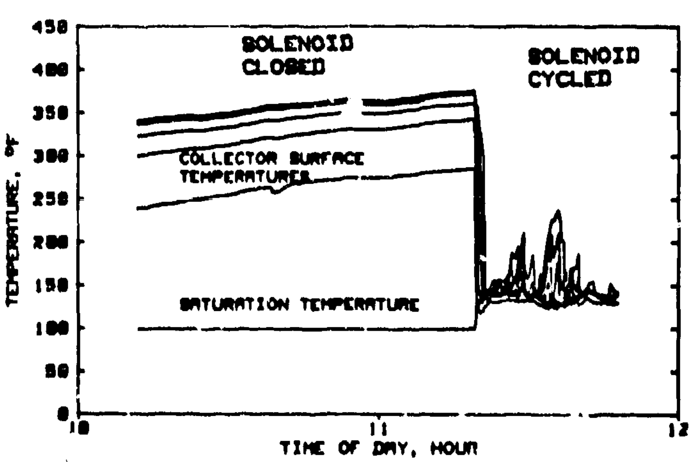

Fig. 12. Collector and saturation temperatures on August 28, 1983. Manual operation of the solenoid in the self-pumping configuration.

CONCLUSIONS

The data we accumulated to date have shown that vapor-transport systems can work quite well. Because they experience no heat loss at night, they should be able to outperform most other passive systems. Pumped-liquid return configurations offer the best performance of such systems. By proper design and placement of collectors and condensers, passive-return configurations should approach the performance of pumped configurations. In addition, self-pumping configurations, if they can be made to work reliably and efficiently, should hold great promise for performance, versatility, and economy. With such a configuration, storage units could be much simpler, as the liquid would be pushed back out the top of the container, thus eliminating any pass-through at the bottom of the device. Leak-tight storage tanks could be built with plastic liners.

ACKNOWLEDGMENTS

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REFERENCES

D. A. Neeper and R. D. McFarland, "Some Potential Benefits of Fundamental Research for the Passive Solar Heating and Cooling of Buildings," Los Alamos National Laboratory report LA-9425-MS (August 1982).

J. Swisher, "Active Charge/Passive Discharge Solar Heating Systems: Thermal Analysis and Performance Comparisons," Solar Energy Research Institute report SERI/TR-721-1104 (June 1981).

R. D. McFarland, "Passive Test Cell Data for the Solar Laboratory, Winter 1980-81," Los Alamos National Laboratory report LA-9300-MS (May 1982).

R. D. McFarland, J. C. Hedstrom, J. D. Balcomb, and S. W. Moore, "Passive Test Cell Results for the 1981-82 Winter," Los Alamos National Laboratory report LA-9543-MS (October 1982).

P. Tamburini, "'T-SYSTEM' Proposal of a New Concept Heat Transport System," 3rd Initial Heat Pipe Conference. Palo Alto, California (May 1978).

G. P. Wachtell, "Self-Controlling, Self-Pumping Heat Circulation System Study," Franklin Research Center report C4772-2 (July 1978).