✱c.2

SERI/TP-34-202

[redacted]

OVERVIEW OF DESICCANT COOLING SYSTEMS AND THEIR STORAGE REQUIREMENTS

BENJAMIN SHELPUK
DOUGLAS W. HOOKER

PRESENTED AT SOLAR ENERGY STORAGE OPTIONS
A WORKSHIP SPONSORED BY DOE,
CONSERVATION AND SOLAR
APPLICATIONS DIVISION

SAN ANTONIO, TEXAS

MARCH 19-20, 1979

Solar Energy Research Institute

1536 Cole Boulevard
Golden, Colorado 80401

A Division of Midwest Research Institute

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

AN OVERVIEW OF DESICCANT COOLING SYSTEMS AND THEIR STORAGE REQUIREMENTS

By

Benjamin Shelpuk and Douglas W. Hooker
Solar Energy Research Institute, Golden, Colorado

One of the building space cooling approaches being pursued in the National Solar Energy Program is the open cycle or desiccant approach. This approach can be implemented through the use of several processes although most of the work thus far uses the process of physical adsorption. Desiccant cooling offers the advantage of any open cycle process, namely the elimination of a heat transfer requirement between the cooling process and the building air. In addition:

- It has the potential for easy integration with passive cooling systems.
- It can accommodate a wide range cooling capacity without significant loss of performance.
- It uses inexpensive materials and has the potential to be manufactured at low cost.
- It usually uses air and inert inorganic materials and thus may not present corrosion or environmental problems.
- It can tolerate air leakage and be easily serviced, thus making its maintainability and reliability attractive.
- It can tolerate a wide range in solar input and still generate a usable output.

Although many desiccant materials can be used for adsorption of water vapor from air, attention is being focused on molecular sieve and silica gel.

Molecular sieve has better adsorption characteristics at low relative humidities or at high temperatures. Hence, dehumidifiers using molecular sieves can operate successfully in the adiabatic mode where both the dehumidified air and the desiccant bed are at high temperatures. Molecular sieves, however, require relatively high regeneration temperatures (150°C) for desorbing. In the context of solar energy application, it means using high-performance collectors or a solar system combined with an auxiliary heat source.

Silica gel, on the other hand, can be desorbed at relatively low temperatures. Hence, silica gel dehumidifiers can utilize simple flat plate collectors for regeneration. However, since silica gel also has good adsorption capacity only at low temperatures, its adsorption capacity decreases rapidly as the bed temperature increases. The performance of a silica gel bed is improved if the adsorbent is maintained at a low temperature during dehumidification by the removal of the heat of adsorption.

DESICCANT SYSTEM ALTERNATIVES

The general configuration of desiccant cooling systems is shown schematically in Figure 1[1]. The process air stream is shown by the horizontal stream at the top of the Figure. Room air is dried in the desiccant bed at right side of the diagram, sensibly cooled to close to the ambient wet bulb in the regenerator, and then evaporatively cooled in the humidifier. The reactivation stream starts at the lower left of the diagram with evaporative cooling of ambient air, followed by heating in the regenerator and solar heater before the stream is used to dry or reactivate the drier bed.

The major, unique component in all desiccant cooling systems is the drier bed. The function of this bed is to remove moisture from the air which is being processed in the system. If this step can be accomplished without a substantial fraction of the heat of condensation remaining in the process stream, all of the cooling in the cycle is completed. The following isoenthalpic evaporative process simply converts latent capacity into sensible cooling.

The various ongoing projects in desiccant cooling can be described in terms of the approach they take to the drier bed design. Four concepts are described in this paper and depicted in Figures 2 to 5. A comparison of the four is summarized in Table 1.

Table 1

Dehumidifier Bed Concepts

Approach	Fig.	Material	Advantages	Concerns
rotary axial flow	2	molecular sieve	• compact design • prototype model exists	• requires gas boost • large auxiliary power
rotary radial outflow	3	silica gel	• reduced auxiliary power • low temperature reactivation	• silica gel without cross cooling
cross-cooled fixed bed	4	silica gel	• low temperature reactivation • compact size	• added auxiliary power in cooling

liquid spray	5	lithium chloride	• minimum auxiliary power	• mass transfer rates
			• potential for simple collectors	• loss or contamination of the desiccant

ROTARY AXIAL FLOW SYSTEMS

The Institute of Gas Technology (IGT) is developing a solar desiccant cooling system which employs a molecular sieve dehumidifier wheel and a natural-gas-fired burner to supplement the delivered solar energy. The desiccant wheel is constructed from a specially made composite paper containing asbestos fibers and molecular sieve. Part of the current work effort is to find a replacement material for the asbestos matrix.

As shown in Figure 2(a)[2], a rotary desiccant wheel is divided by a partition into two balanced-flow segments, one for moisture removal and the other for the passage of the high temperature (approximately 125°C) reactivation air stream. These two streams flow in opposite directions. Figure 2 (a) shows the simplest desiccant wheel configuration.

Figure 2(b)[2] shows two design improvements currently in development to optimize the performance of the basic desiccant wheel. These improvements are a purge section and a two-stage reactivation temperature.

As the desiccant wheel crosses the transition from the reactivation zone to the process zone, the desiccant material is hot and dry. Thus, little or no dehumidification occurs in the first portion of the process zone (10 to 15°) until the desiccant is sufficiently cooled. The purge zone is included to remove heat from the initial process section of the wheel so that it can be recycled to the reactivation stream. The net result is a lower primary energy requirement for the reactivation stream and lower average process stream humidity and temperature.

The two-stage reactivation temperature scheme can result in a significantly drier process stream at the expense of a slightly higher process stream temperature. The portion of the wheel moving from the process side to the reactivation side is wet and warm. Thus, the reactivation stream temperature in the first part of the reactivation zone need not be as severe as in the later stages of reactivation when the wheel is relatively hot and dry.

Implementation of these improvements has the potential to significantly improve the capacity and efficiency of the state-of-the-art axial flow wheels. In addition, two-speed fan operation should significantly reduce auxiliary power requirements by reducing the part-load power draw.

Prototypes employing axial flow desiccant wheel dehumidifiers have been field tested. The current program includes the laboratory testing of a desiccant cooler with improved design features resulting from the ongoing development effort. Test results should be available in the Fall of 1979.

ROTARY RADIAL OUTFLOW SYSTEM

AiResearch Manufacturing Company is developing a solar desiccant cooler which features a rotary radial outflow configuration with a granular silica gel drier bed and a screen regenerator. The design is specifically configured to reduce auxiliary power requirements of the drier and heat exchanger components by increasing their face area and reducing the airflow length.

A top view of the dehumidifier along the axis of rotation is shown in Figure 3[1]. The solar heater is located between the dryer and regenerator. Warm, humid air from the residence is directed to the adsorbing side of the rotary dryer. Water is adsorbed from the air stream, which is heated in the process. The air is then cooled in the rotary regenerator. The specific humidity of this air stream is sufficiently low so that its dry bulb temperature can be lowered by adiabatic humidification to levels adequate for sensible cooling while retaining reasonable latent cooling capacity.

Ambient outside air is used to regenerate the sorbent bed and cool the rotary regenerator. First, this stream is humidified adiabatically and circulated through the rotary regenerator. About one-half of this air is then exhausted from the dehumidifier without flowing through the dryer. The remainder is heated by solar thermal energy and passed through the dryer to desorb the desiccant.

A minor amount of air directly from the ambient is circulated through the hot portion of the sorbent bed as it rotates from the desorbing zone to the adsorbing zone. In this manner, the bed is cooled to a temperature level where it can adsorb moisture when exposed to the return air from the residence. This preconditioning air flow is then used to preheat the bed prior to desorption, thus reducing the solar thermal energy necessary for this process.

This program will include the laboratory testing of a dehumidifier bed and a 1.5 ton prototype cooling system. The tests are scheduled for completion in the Fall of 1979.

CROSS-COOLED FIXED BED SYSTEM

The Illinois Institute of Technology (IIT) is currently performing research and development work on a solar desiccant cooling system which utilizes silica gel in a cross-cooled dehumidifier. Their present system consists of a cross-cooled dehumidifier constructed of paper-like sheets of silica gel in a teflon matrix. This concept is represented schematically in Figure 4[3].

The cooling system consists of two cross-cooled dehumidifiers of equal size used in conjunction with evaporative coolers. One dehumidifier removes moisture from the process air while the other is being regenerated with solar energy. The process air leaving the cross-cooled dehumidifier in the dehumidification mode is dry and only moderately warm. Cooling is achieved by the evaporation of water. In the adsorbing cycle, the air from the conditioned space is passed through the process channels of the dehumidifier, with the heat of adsorption removed by cross-cooling with either ambient or room air. In the desorbing cycle, the saturated bed is regenerated by hot air from flat-plate solar collectors. A rock-bed storage system is provided for storing the excess collected energy. There is also the possibility of storing excess cooling capacity in a rock-bed storage.

Much of the work underway on this concept is still basic research and development, including development of mathematical analysis methods and the testing of silica gel sheets and small models of the cross-cooled dehumidifer bed. However, a one-half-ton prototype cooling system will be built and tested under the current program.

LIQUID DESICCANT (ABSORPTION PROCESS) SYSTEMS

A solar cooling concept which is gaining interest is the continuous, open cycle absorption cooler. This cycle has received considerable attention by researchers in the U.S.S.R. (References 4 and 5). The absorption cycle is similar to its closed cycle counterpart except that the weak absorbent solution is regenerated by losing refrigerant to the earth's atmosphere instead of recovery in the condenser as in a closed system. Cooling takes place by evaporating refrigerant from an external source in the evaporator rather than obtaining refrigerant from the condenser. The condenser is, therefore, eliminated in the open cycle. However, an external source of refrigerant must be available. Whenever the refrigerant is water, the open cycle becomes very feasible.

A schematic of an open cycle absorption cooling system similar to that built and operated by the Soviet investigators is shown in Figure 5[6]. The weak absorbent solution is heated and subsequently concentrated in the solar collector, which is open to the atmosphere. The strong regenerated solution leaves the collector and passes through a liquid column. The purpose of this column is to allow the strong solution to efficiently go from atmospheric pressure to reduced pressure. The strong solution then passes through a regenerative heat exchanger on its way to the absorber. In the absorber, the strong solution absorbs water from the evaporator, maintaining the reduced pressure required by the evaporator. The heat of absorption for the water-absorber solution is removed by heat transfer to a cooling tower loop. In the evaporator, water from an external source is evaporated at reduced pressure with the energy supplied by heat from the cooled space. The resulting weak solution is pumped from the absorber back to atmospheric pressure through the regenerative heat exchanger and to the collector, completing the cycle. The vacuum pump shown is necessary to deaerate the solution after it has been exposed to the atmosphere.

An important aspect in the operation of the open cycle refrigeration system in Figure 5 is the unique relationship between collector performance and system performance. The useful energy output of both the collector and the cooling system is the evaporation of water. For every pound of water evaporated in the collector, one pound of water can be evaporated in the evaporator and absorbed in the absorber. Thus, the water evaporation rate from the collector determines the amount of water which can be evaporated in the evaporator and, hence, determines cooling system performance. Various approaches have been proposed for achieving solution concentration either in a dual purpose collector or in direct coupled concentrator. The heat and mass transfer performance of this subsystem is a primary issue in the performance of an absorption system.

The open cycle absorption process is under evaluation by SERI to determine the potential of the concept for providing solar cooling and to establish research priorities for reaching that potential. Although some research and development work has been performed, a great deal more effort is required to develop a viable residential or commercial cooling system.

PERFORMANCE PREDICTIONS

During the past several months, SERI has begun the process of developing computer models which can be used to evaluate the performance of the various desiccant cooling systems. A study has been performed by SERI with a solar desiccant cooling system employing an early version of an axial flow desiccant wheel like that shown in Figure 2(a)[7]. The study was an evaluation of residential solar cooling potential so that optimum cooler/collector system sizes, climatic conditions, and economic parameters could be identified. The steady-state performance of the desiccant cooling system was analyzed, and a dynamic analysis was performed for five U.S. cities using hourly weather data to determine seasonal solar desiccant cooler performance.

A desiccant cooler shows the most sensitivity to regeneration temperature. Figure 6 shows that the cooler capacity varies greatly with regeneration temperature and that the system COP peaks around 75 to 80°C. The capacity of such a machine increases with temperature beyond the maximum COP point and selection of a design temperature requires a tradeoff between these parameters.

The annual performance of the solar desiccant cooler is the determining factor as to whether the cooler can beneficially be applied to residential cooling. Of the five cities studies by SERI, Washington, D.C. represents the best type climate for solar desiccant coolers. This is true because maximum cost-effectiveness occurs when a system is sized for solar heating and the cooling is added as a complementary summertime use of the collected energy. Thus, the chiller must be sized to operate efficiently with the available collector area, and the load must be reasonably consistent with the resulting capacity. The sunny parts of the middle U.S. generally meet these constraints. For a solar desiccant cooler in Washington, D.C. with an electrically-driven vapor compression cooler as a back-up, a desiccant cooler of 4.5 kW (1-1/4 tons) capacity could be driven from 35 m^2 of solar collectors. The storage subsystem used is a pebble bed of 14 m^3 (0.4 m^3/m^2 of collector). The annual desiccant cooler COP would be in the range of 0.5 to 0.6, and the energy efficiency ratio (EER) could be in the range of 13 to 18.

These results are shown in terms of cost and displaced fossil fuel in Figure 7. They show that it should be beneficial to use solar desiccant coolers in residential applications. Fossil fuel energy is conserved by employing solar desiccant cooling in place of conventional systems. According to evaluations made by the DOE cooling contractors, the potential exists for even more efficient systems with designs of the type described in the first part of this paper. It is not yet clear which design can achieve the most cost-effective air conditioning system. The promise of an efficient solar desiccant cooler which can conserve fossil fuels and effectively compete with conventional air conditioning methods continues to be pursued aggressively and supported by a test and analysis program.

STORAGE CONTRIBUTION

The contribution of thermal storage in desiccant cooling systems is being studied by SERI. Three cases currently under consideration include desiccant cooling systems with no storage, a pebble-bed storage system with a volume of 0.4 m^3/m^2 of collector area, and a two-phase storage system with a volume of 0.02 m^3/m^2 of collector area.

Although only very preliminary results are available, it appears that the percentage of cooling capacity which is supplied from storage is minimal. While a significant fraction of the energy utilized in the desiccant cooler is supplied from storage, the overall COP tends to be lower in this case than when the cooler operates directly from the solar collector output. In addition, the EER of the system without storage is larger because the pressure head associated with putting heat into and taking heat out of storage is eliminated. The conclusion that one must reach from the comparisons performed to date is that storage plays a fairly minor role in the performance of the desiccant system under the operating constraints included in this study.

Qualitatively, however, it appears clear that an improved storage subsystem (for example, phase change material packaged in the form of pellets and melting in the range of 75 to 90°C) could help achieve improved system performance in two ways. First, it would reduce the maximum collector temperature experienced during the operation of the system. Secondly, since less material would be needed for a given storage capacity, the storage bed would have a smaller air pressure loss and, therefore, the system should not experience a significant penalty in air-system parasitic losses.

Because the most cost effective desiccant cooling system is one that is sized to meet the average rather than peak cooling demands of the building, there is seldom excess cooling capacity or excess thermal energy available from the collectors. Thus, even an improved storage sub-system does not offer significant advantage.

Given the constraints of projected solar system performance and cost and fossil energy costs assumed in the SERI study, it appears clear that a system sized to meet average demand and backed-up with conventional cooling is the most cost effective approach for desiccant systems. However, if off-peak pricing policies or fossil energy unavailability for building cooling forbids this strategy, then phase change storage for an air system with the phase change occurring in the temperature range of 75 to 90°C appears to be the most attractive system. Preliminary analysis indicates that if a strategy is pursued which supresses the operation of the cooling system before the hour of 12 o'clock (noon) either by allowing the building space temperature to rise or by providing the required cooling from an auxiliary source, then all of the cooling requirements can be satisfied during the utility peak demand hours from the combination of solar and the stored heat. In both cases, there should be an advantage in using a 75°C phase change storage system over a conventional rock bed alternative.

OTHER STORAGE CONSIDERATIONS FOR DESICCANT SYSTEMS

Two additional storage system possibilities should be mentioned with regard to desiccant systems. The first would be unique to desiccant systems and the second probably has much in common with other cooling approaches.

A desiccant cooling system is producing refrigeration capacity in the form of dry air. This capacity, which is latent cooling capacity, can be converted to sensible capacity in an evaporative cooler. A potential storage approach would be to produce air drying capacity during those times when there is no demand in the building for cooling. This is most easily accomplished in a batch-type system such as the open cycle absorption cooling system shown in Figure 5. The strong solution collection tank shown at the bottom of the solar collector could be made large enough so that drying capacity could be provided at those times when the collector is not regenerating the weak solution coming from the absorber. Alternatively, at those times when there is no circulation from the absorber but concentrating capacity exists in the collector, solution from the collection tank can be continuously circulated and concentrated to its full moisture absorbing capacity. This approach is much more difficult to achieve with solid adsorption beds since higher temperatures are required as the bed becomes drier. However, since there are no thermal losses associated with storing drying capacity in a large bed, the storage can be extremely long term and offers the potential of using the solar capacity which exists in early summer when there is no building cooling demands for use in late summer when the demand may exceed the capability of the system to meet it.

A major problem with desiccant systems is that they are usually air systems, and the parasitic power requirements associated with circulating the air are large. If the dryer bed regeneration temperature drops because of reduced insolation, then the cooling capacity and COP of the chiller become low, even though the electrical power being used stays constant. The result is a sharply decreasing value of EER. There then becomes a cut-off temperature below which it is not profitable to use the solar energy being supplied. In the studies which SERI completed, a cut-off temperature of 45°C was used, although it would appear from the data in Figure 6 that a value in the range of 50-55°C might be more appropriate since the EER of the system at those temperatures would be equal to the EER of an alternative vapor compression backup. System performance would improve by recovering the energy available from the collector system when it is inadequate to meet the chiller demands, yet still at temperatures above the cut-off temperature. A small phase-change bed in close proximity to the collector system could probably meet this requirement in a satisfactory way. No analysis has yet been done to determine the effectiveness of either of these two storage approaches.

In summary, it can be said that thermal storage does not play an important role in the desiccant cooling systems which are presently being developed, but that there are at least two storage concepts which have potential application in advanced desiccant cooling systems. First, the possibility of long-term storage of air drying capacity in a large bed of desiccant material could extend the usefulness of the solar system. Secondly, a requirement exists for short term thermal capacity in the temperature range of 75 to 90°C to satisfy two requirements: (1) eliminating demand for utility power at peak load periods, and (2) for the purpose of useful energy recovery at those times when the output of the collector system is inadequate to meet chiller requirements. Hardware development in these areas should be backed up with systems analysis which clearly defines the requirements and advantages of these approaches.

REFERENCES

1. AiResearch Manufacturing Company of California, "Technical Progress Report - Development of a Solar Desiccant Dehumidifier," Volume 1, Report No. 78-14957-1, March 31, 1978.

2. Wurm, Jaroslow, et al., "Solar - MEC Development Program - Project 9103 Third Quarter Progress Report," Institute of Gas Technology, Report No. COO-4495-13, December 1978.

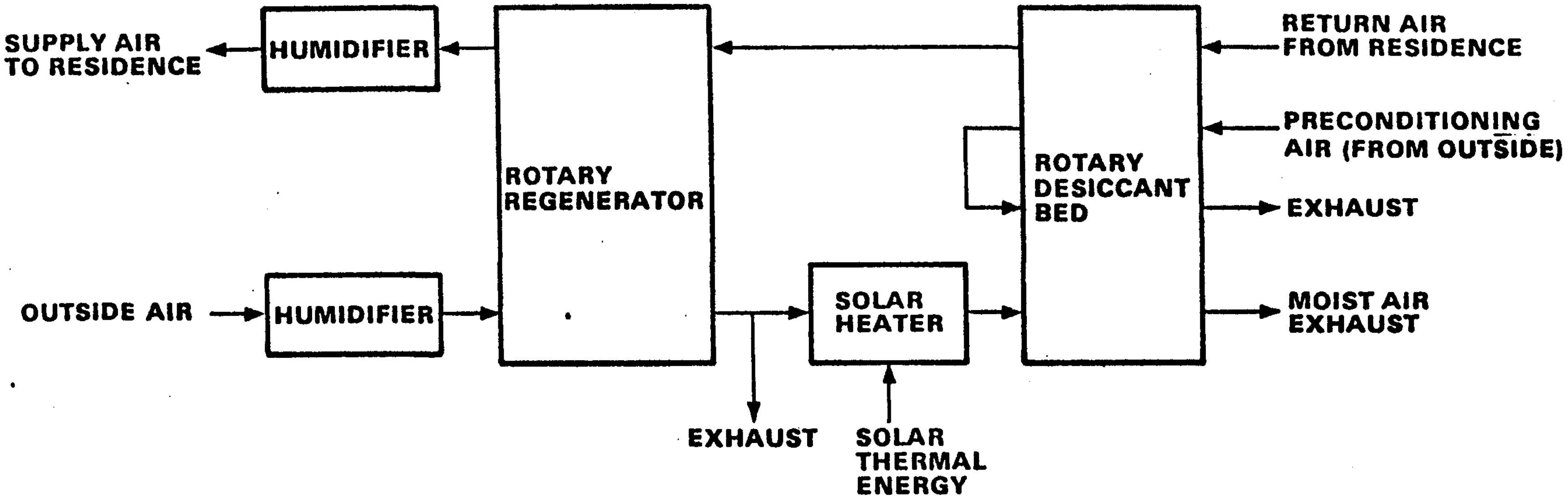
3. Illinois Institute of Technology, "First Semi-Annual Progress Report on Development of a Solar Desiccant Dehumidifier," June 10, 1978.

4. A. Kakabaev and A. Khandurdyev, "Absorption Solar Refrigeration Unit with Open Regeneration of Solution," Geliotekhnika, Vol. 5, No. 4, pp 69-72, 1969.

5. V. A. Baum, K. Kakabaev and O. Klyshchayeva, "Technico-Economic Characteristics of Solar Units for Cooling Buildings," Third Soviet-American Seminar on General Aspects of Solar Energy Technology, 1977. (Unpublished)

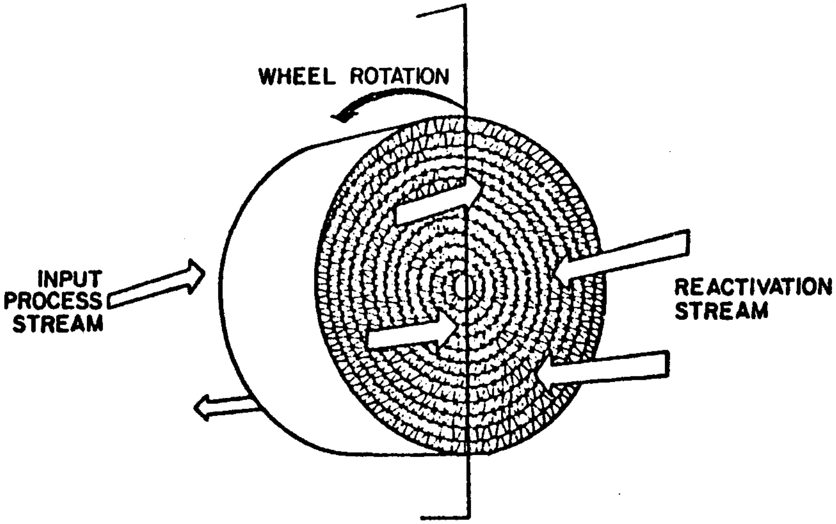
6. Collier, R. K., "The Analysis and Simulation of an Open Cycle Absorption Refrigeration System," Los Alamos Scientific Laboratory, Report No. LA-UR-78-1729, undated.

7. Shelpuk, Benjamin C., Douglas W. Hooker, Gary J. Jorgensen, and Carl C. Bingham, "Seasonal Performance Simulations and Economic Analyses of Solar Heating and Disc-Type Desiccant Cooling Systems," Solar Energy Research Institute, Report No. SERI/TR-34-090 (to be published).

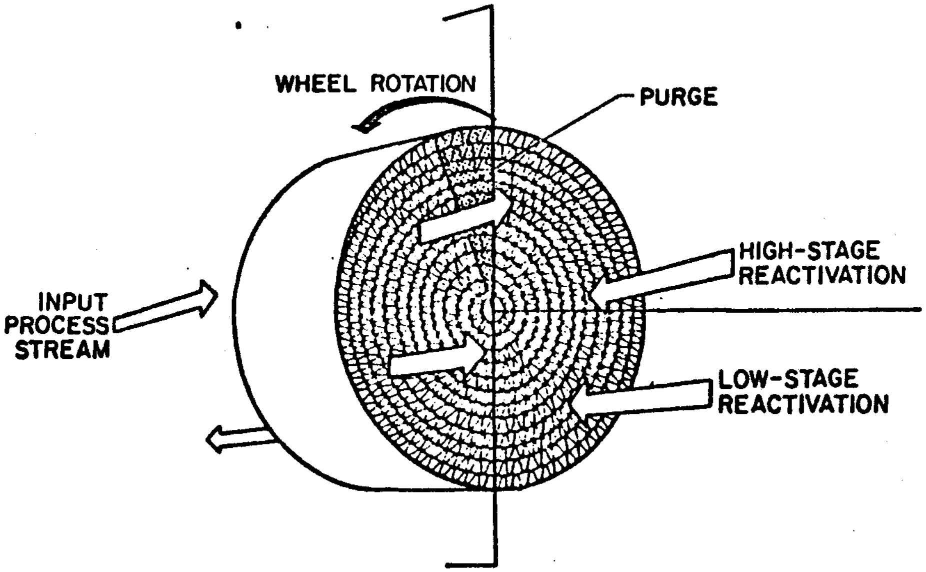


Desiccant Cooling System Schematic

FIGURE 1 [1]

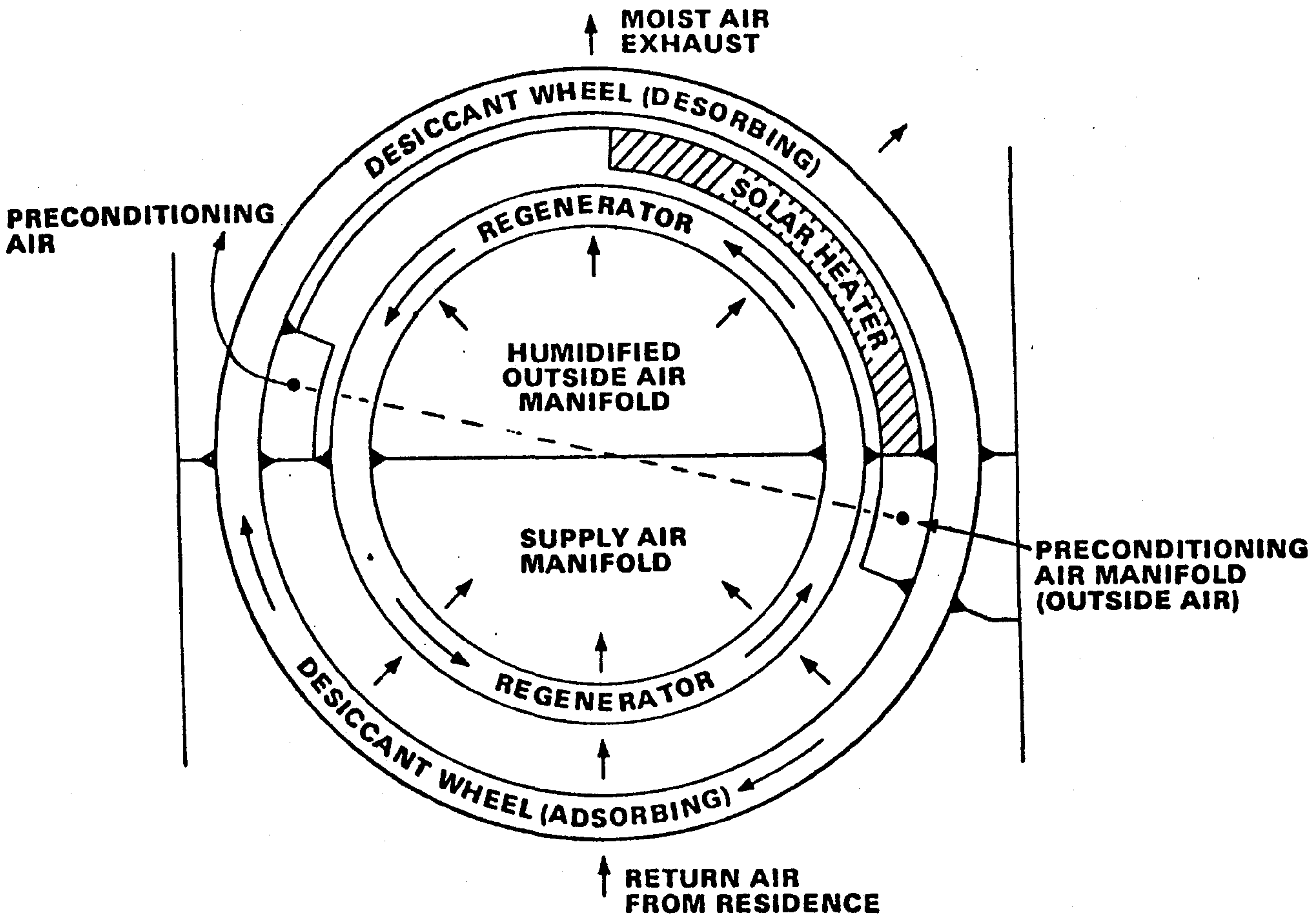


(a) Basic Desiccant Wheel



(b) Improved Desiccant Wheel

FIGURE 2 [2]



Rotary Bed Dehumidifier Arrangement

FIGURE 3 [1]

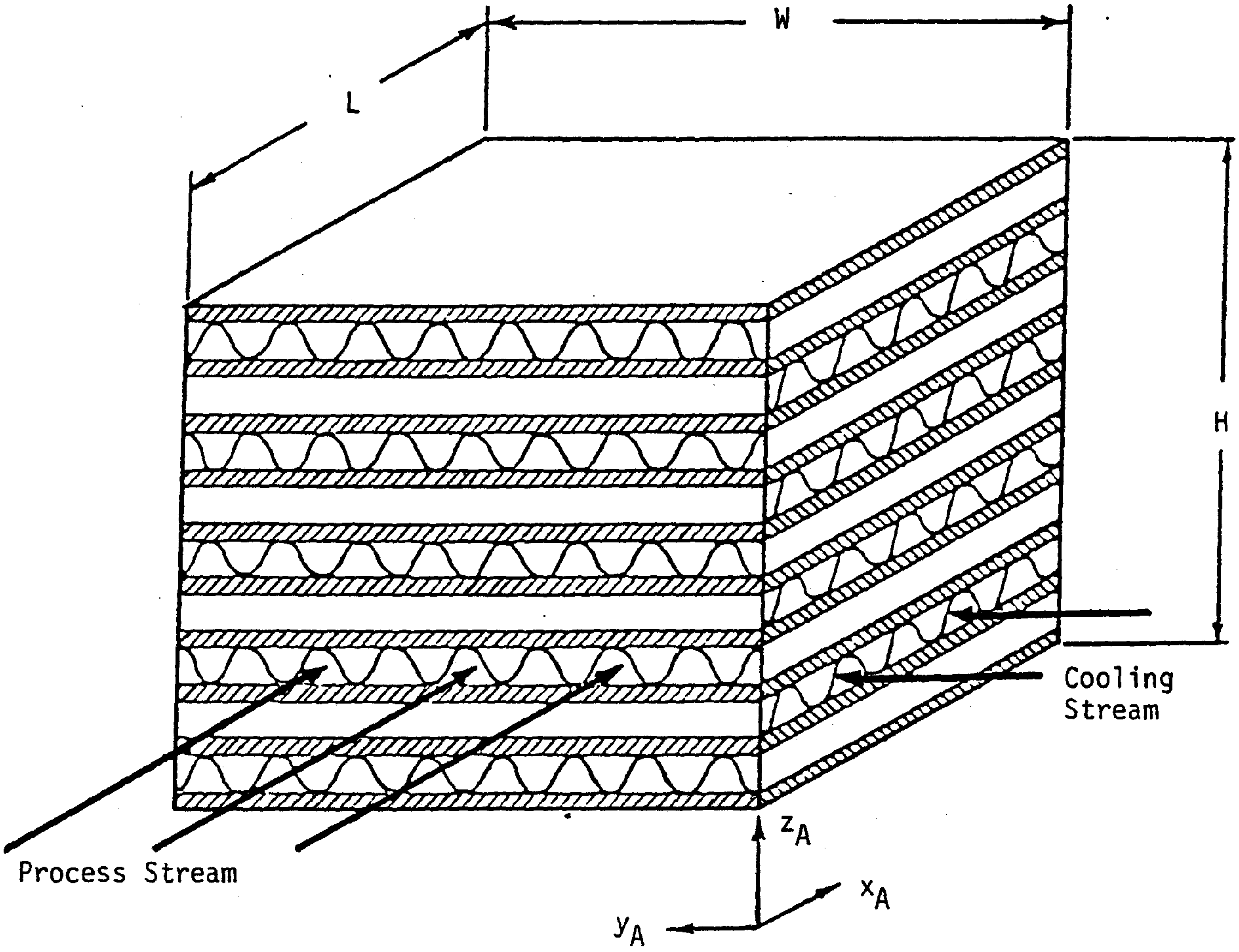


FIGURE 4

Schematic of Cross-Cooled Dehumidifier [3]

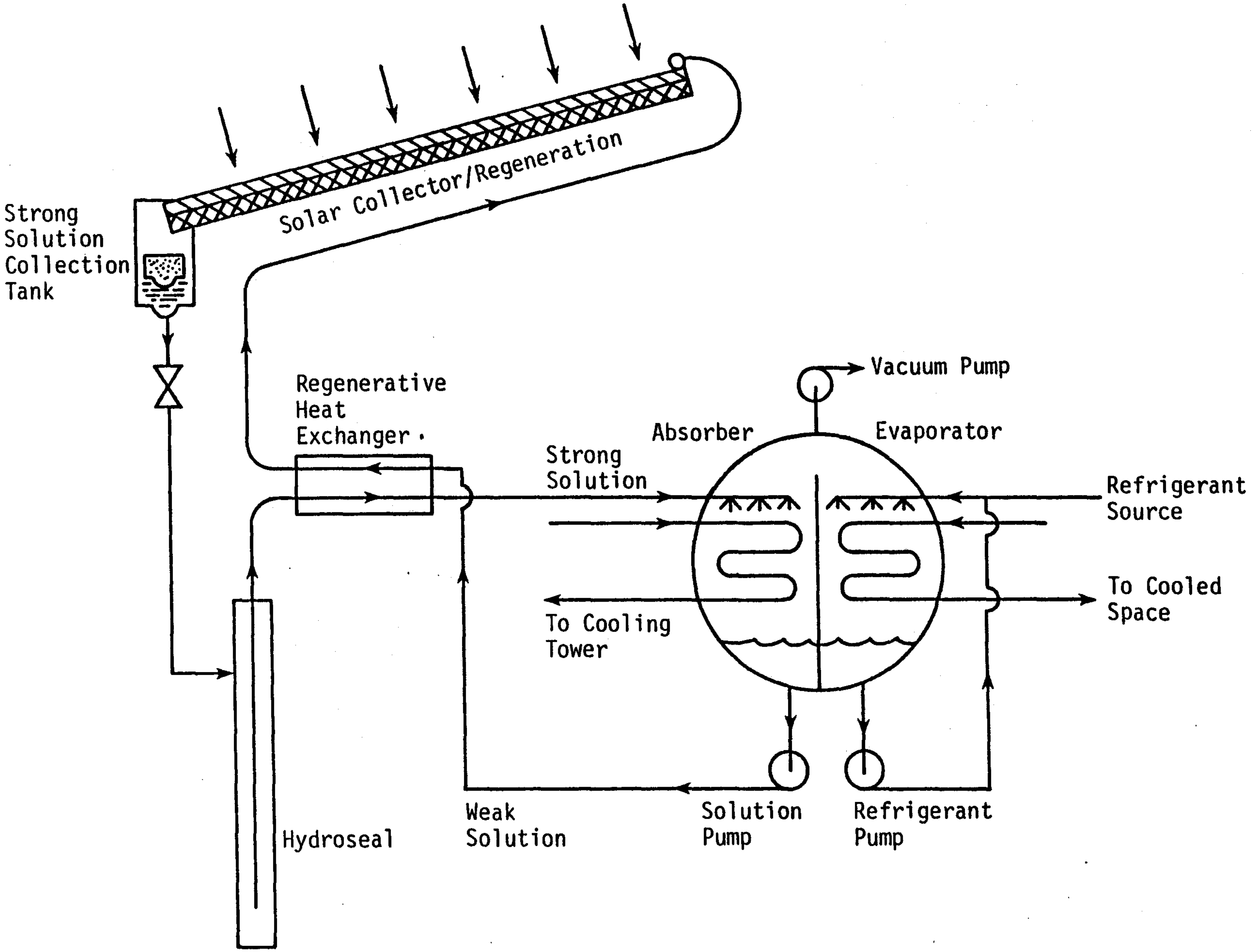


FIGURE 5

OPEN CYCLE ABSORPTION COOLING SYSTEM [6]

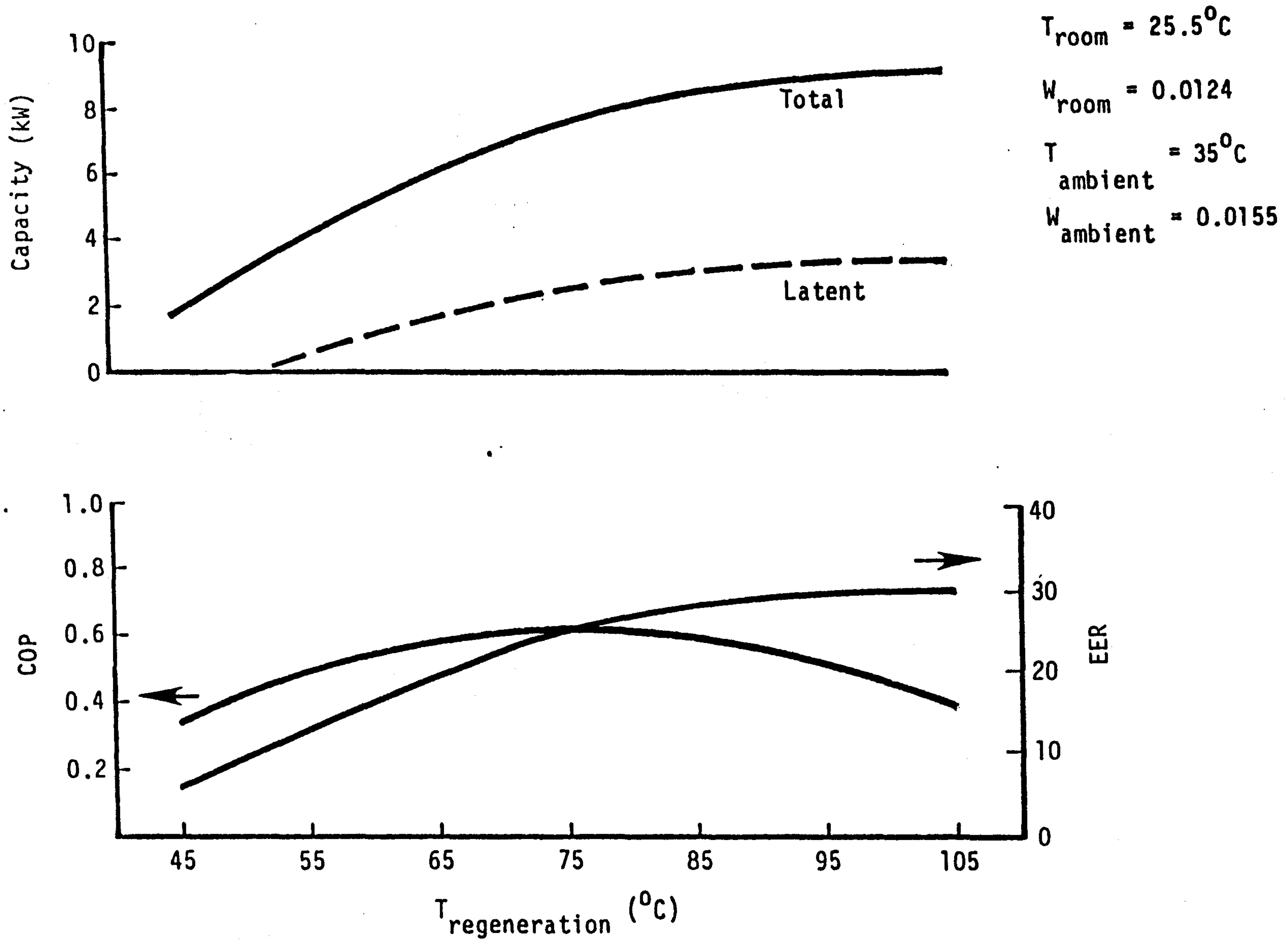


FIGURE 6

STEADY-STATE SENSITIVITY TO REGENERATION TEMPERATURE,
NOMINAL 9.0 kW CAPACITY [7]

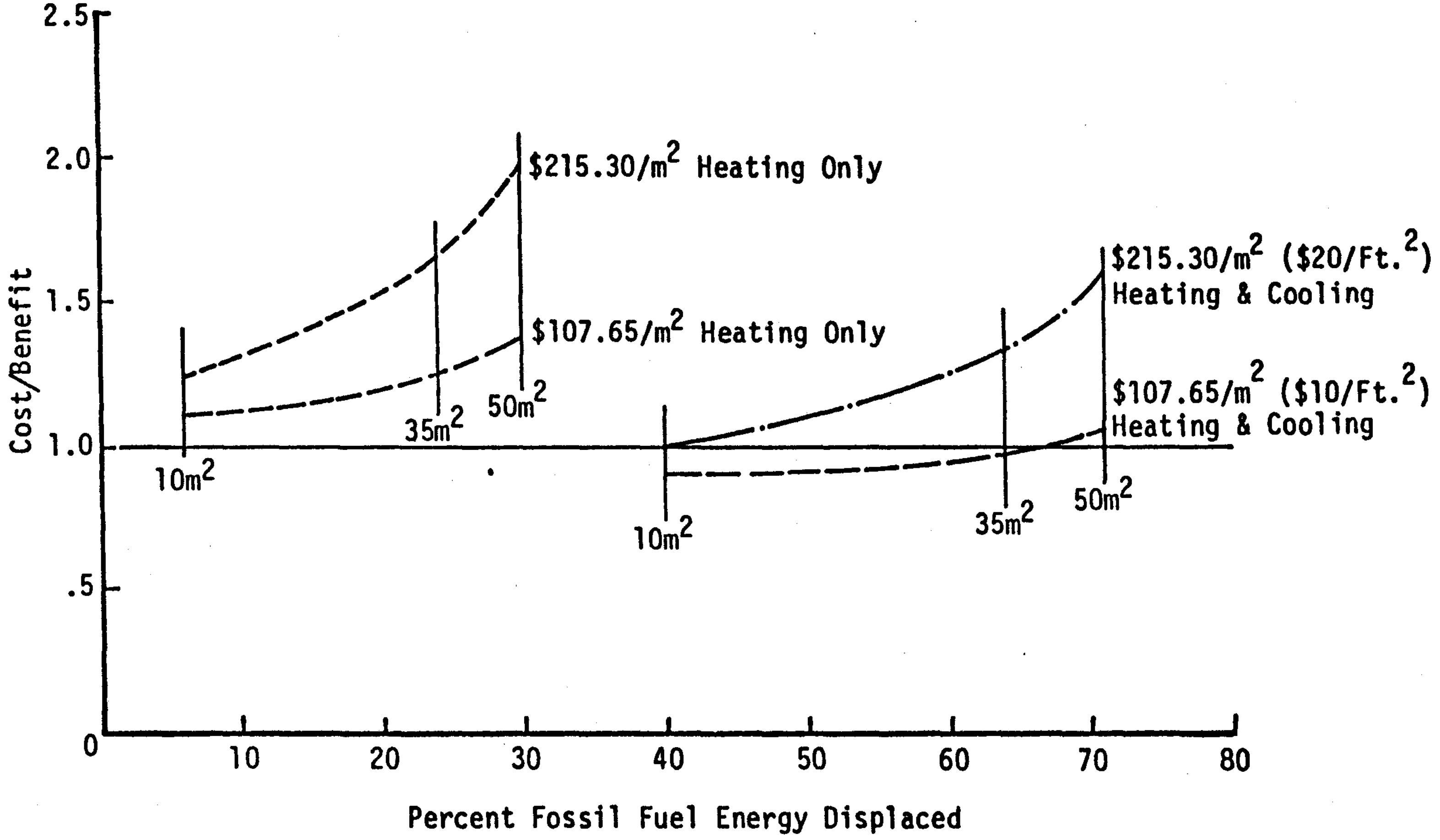


FIGURE 7

COST/BENEFIT VERSUS FOSSIL FUEL ENERGY DISPLACED, WASHINGTON, D.C., 4.5 kW DESICCANT COOLER WITH AUXILIARY, 1985 BASE YEAR [7]

DISTRIBUTION LIST

No. of Copies	Distribution
1	Department of Energy: DOE, SERI Site Office Contracting Officer Attn: Charles M. Skinner
1	Chicago Operations Office Interim Program Division Attn: M. E. Jackson
1	Division of Solar Technology Office of Asst. Director for Administration Attn: R. H. Annan
1	Office of Asst. Secretary for Conservation & Solar Applications Attn: R. Scott
1	Office of Solar, Geothermal, Electric & Storage Programs Attn: Martin Adams
1	Division of Energy Technology Administration Attn: S. Hansen
1	Division of Distributed Solar Technology Office of the Director Attn: R. San Martin
1	Division of Central Solar Technology Office of the Director Attn: H. Coleman
1	Division of Energy Storage Systems, ETS Office of the Director Attn: G. Pezdirtz
1	Division of Planning & Energy Transfer, ETS Office of the Director Attn: Leslie Levine
1	Wind Energy Systems Attn: L. Divone