COOLING EFFECT USING HYBRID SOLAR DESICCANT COOLING SYSTEM

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ABSTRACT

Using excess summer heat from solar collectors to drive desiccant cooling systems is often proposed. A two wheel desiccant system using solar heat for desiccant regeneration is typically discussed. The two wheel system uses a desiccant wheel that is "matched" with a heat exchanger wheel. The heat exchanger recycles heat for the desiccant regeneration and improves system efficiency. These systems are generally limited to delivering warm dry air or cool humid air in most parts of the US.A newly patented desiccant cooling cycle creates two dry air streams. This new cycle uses indirect evaporative cooling of one air stream to cool the second stream. Additional direct evaporative cooling allows cool and dry air to be delivered to the building. Regeneration exhaust heat can provide water heating. Combining the system with a new solar air heating system should provide a significant solar heating, cooling, and hot water delivery system. Desiccant systems are presently used in industrial air-drying applications. There are solid systems marketed by Bry-Air® and Cargocaire® and liquid systems marketed by Niagara® and Kathabar®. The first two use a desiccant-laden wheel in which air may flow in the axial direction only. The solid desiccant (lithium chloride salt or silica gel) is impregnated into the wheel material or encapsulated as a packed bed. Air to be dried flows through one side of the wheel, while the desiccant on the other side of the wheel is being dried by an externally heated air stream. These two air streams must be kept physically separate in order to maintain the distinctly separate functions of air drying and desiccant regeneration.

I. INTRODUCTION

Low temperature heating dominates all residential, commercial, and industrial end uses of energy within buildings. Nearly 61% of the energy used across all sectors of the economy is for low temperature heating uses. These heating end uses include space heating, industrial process heating, water heating, boiler heating, and clothes drying.The second greatest energy end use is for cooling. Another 13% of all building energy end use is for refrigeration or space cooling. In the late 1990's, the combination of all heating and cooling energy end uses cost US consumers nearly $180 billion per year.Most of this energy use requires the consumption of fossil fuels. In most cases, the energy conversion devices, such as boilers or electric heat pumps, operate at low efficiency compared to the fuel they consume. In almost all fossil energy heating and cooling systems, the conversion from the primary fuel (gas, oil, coal, etc.) to heating or cooling is done at less than 100% efficiency. This is often described as a coefficient of performance of less than 1.0. (COP < 1)

However, there are three technologies that operate at what can be called super efficiencies. These technologies convert primary energy into heating or cooling capacity with COP's between 2 and 5. These three technologies include solar thermal heating, evaporative cooling, and desiccant drying. By using a combination of simple, low energy, physical phenomena, and widely distributed low cost energy and waterresources, these three technologies are recognized as super efficient at delivering heating and cooling. Solar air and water heating system have been shown to have a COP of 4 or greater at providing solar heat with little expense in fan or pumping primary energy. Evaporative cooling systems have been demonstrated to operate at a COP of 5 when used in dry conditions. Desiccant system with evaporative final cooling can operate at a COP of more than 2.

However, the application of these technologies has been restricted by their individual limits in responding to:

1) High temperature or
2) High levels of humidity, or
3) Harsh economic realities caused by seasonal idleness of expensive heating and cooling equipment.

Evaporative cooling is only effective for comfortable cooling in dry climates. When outdoor humidity rises, the cooling capability of direct evaporative systems declines unless occupants are willing to suffer with high humidity. Even in climates that suffer only a few weeks of high humidity, most consumers will select low efficiency compression refrigeration cooling systems for comfort cooling. Since most customers buy only one system, the low COP compression systems will be the only cooling systems installed. Thus, the rest of the year's super efficient evaporative cooling capacity is lost for lack of a few weeks of dry air. Solar space heating suffers a similar fate due to the typical high cost of flat plate collector systems and the lack of useful energy cost savings delivered in the summer months. The seasonal decline in cost savings reduces the overall cost savings the systems can deliver in any given year. This stretches out payback periods for traditional flat plate systems and makes them uneconomic for most space heating applications.

II. LITERATURE SURVEY

Dhar and Singh[1] (2001) made studies on solid desiccant based hybrid air conditioning systems and reported that considerable energy saving can be achieved by using solid desiccant-based hybrid air-conditioning cycles instead of conventional systems using refrigerated cooling coils alone, especially in hot-dry weather conditions. In hot-humid weather conditions energy savings are possible only under high latent load conditions. However, there is a great need to optimize the operating parameters of the desiccant wheel for getting the best performance.Camargo et al [2] (2003) made an attempt on thermo-economic analysis of an evaporative desiccant air conditioning system and revealed that exergetic manufacturing cost (EMC) method will be of powerful tool forthermal systems optimization and take the lowest computational time and easy implementation.

Sharma et al [3] (2009) reviewed on thermal energy storage with phase change materials and applications, analyzed large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications.

Pesaran et al[4] [Pesaran, 1992] after initially outlining the basic principles of desiccant cooling system, claimed that in 1990 about US$ 22 billion were spent in air conditioning of residential and commercial buildings. A substantial part of that money could be saved by switching to desiccant cooling systems as these systems required low grade heat. According to them there were notable advantages of using desiccant system for cooling, such as improved indoor air quality (IAQ), reduction in the use of CFC's and better control of indoor humidity. They claimed that although the cycle efficiency of system was less than one but it used low grade heat which could be obtained from solar or waste heat and offer a better solution than the vapour compression or vapour absorption cycle using electricity or steam respectively.In a follow up paper Hofker et al [5] [Hofker, 2001] in their research article described the experimental work performed on a solar thermal energy powered desiccant cooling system installed at a school in Stuttgart. Extensive parametric studies conducted on the DCS revealed the effect of individual components on the system performance. They demonstrated from their experimental work that if regeneration air flow rate was decreased by twenty five percent, the dehumidification efficiency decreased only by seven percent resulting in significant energy saving. Desiccant cooling systems which were controlled to meet the indoor temperature and humidity were simulated for different type of weather conditions. The control strategy consisted of five operation modes - heat recovery mode, ventilation mode, adiabatic cooling mode, desiccant cooling mode and desiccant cooling without Evaporative cooler mode.

III. DESICCANT TECHNOLOGY

A desiccant material naturally attracts moisture from gases and liquid. The material becomes as moisture is absorbed or collected on the surface; but when heated, the desiccant dries out-or-regenerate and can be use again. Conventional solid desiccant include silica gel, activated alumina, lithium chlorate salt and molecular sieves. Titanium Silicate a class of material called 1m, and synthetic polymer are new solid desiccant material design to be more effective for cooling application. Liquid desiccant include lithium chlorate, lithium bromide, calcium chloride and triethylene glycol solution. In a dehumidifier, the desiccant removes moisture from the air, which release heat and rises the air temperature. The air is then cooled by heat re-covers units and cooling devices such as evaporative cooler or the cooling coil of a conventional air conditional. In a standalone desiccant system, air is first dried, and then cooled by a heat exchanger and a set of evaporative coolers. This system is free of ozone-depleting CFC and HCFC refrigerant. In most systems, a wheel containing desiccant continuously dehumidify outside air entering the cooling unit. The desiccant is then regenerated by thermal energy.Supply by natural gas, waste heat, or the sun. A desiccant system can also supplement a conventional air conditioning system. The desiccants remove the humidity load while the evaporator of the air conditioner lowers the air temperature. Generally desiccant wheel are used. Fig.1 shows principle of desiccant cooling.

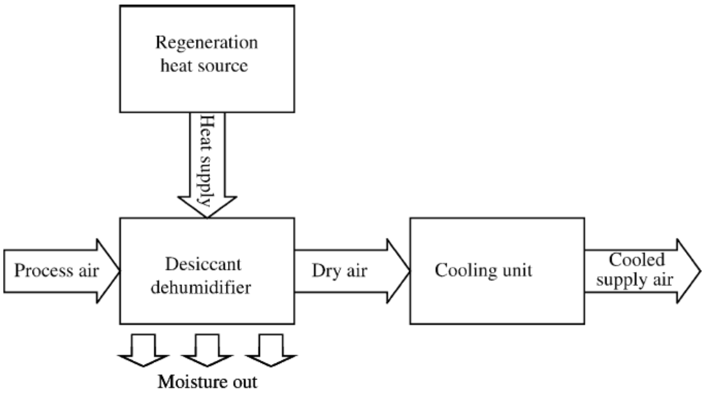

Fig. no.01 Principle of desiccant cooling

3.1. Desiccant Evaporative Cooling System

A typical desiccant cycle can be cost effective when removing humidity from the air. However, regeneration of the desiccant requires heating roughly equal to the energy it provides for dehumidification. When using evaporative final cooling, the system can deliver a range of warm dry air or cool humid air at relatively high COP. A typical two wheel desiccant cycle is shown in Figure 2. The psychometrics for the cycle is shown in Figure 3 along the lines from A to B to C and the “2 wheel limit line”. The regeneration cycle is shown along E, G, I and J. The “2 wheel limit line” in Figure 3 represents the continuum of temperature and humidity possible by evaporative cooling the dry air from point C to D. As shown, the line does not deliver both cooler and drier air than the original state point E. To achieve the necessary cooling that removes both internal and external heat gain and humidity loads, the condition along the line C to D must be substantially cooler and drier than the existing state point E within the building. The line C’ D represents one such cooler drier condition. To achieve this condition usually requires an additional cooling system that completes the final cooling from point C to point C’. Compression refrigeration is most often used for this final cooling in conjunction with a desiccant system for dehumidification. However, in most cases, consumers will buy only one cooling system, a compression system, to meet their entire cooling needs.

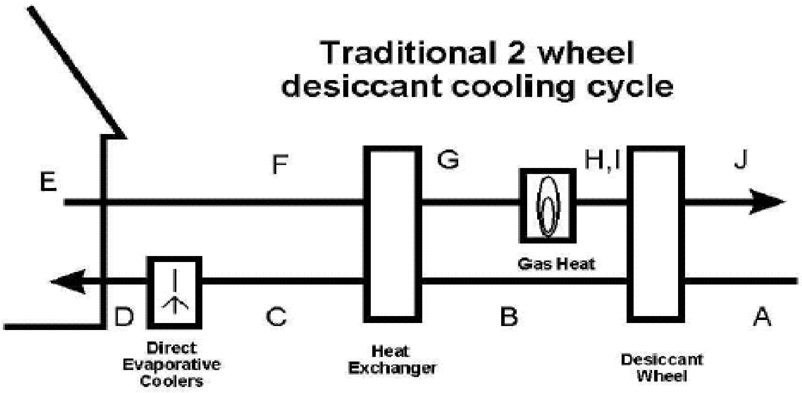

Fig.2: Two wheel desiccant cycle

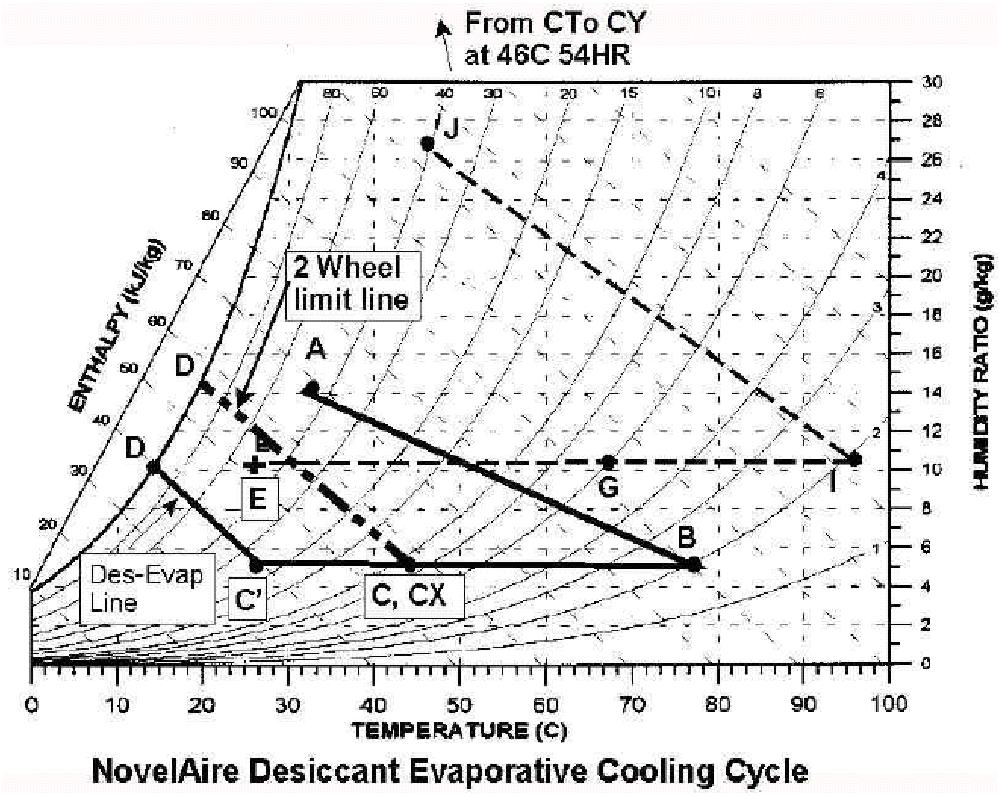

Fig.3: Desiccant psychometrics

3.2 Solar Desiccant Evaporative Cooliong System

With the solar, desiccant, and evaporative cooling industries each targeting different geographic or technological problems, there has been little joint development. Solar thermal work is concentrated on flat plate water heating systems, which are generally not cost effective for space heating applications. In general, the northern climates, with high heating needs, are where solar space heating could deliver the greatest value, but this is also where minimal cooling energy is required in the summer. Evaporative cooling is targeted to the dry southwest. Desiccant cooling is targeted to the humid southeast.Despite the differences in geographic, technological, and economic conditions that favor the limited separate use of individual technologies, there is a potential to draw together the best characteristics of each of these super efficient technologies into one super efficient system. The combined solar desiccant evaporative system can provide a significant portion of the space heating, hot water heating and space cooling needs of residential and commercial consumers.

IV. NEW TECHNOLOGIES

Recent patents in each technology have overcome some of the problems holding back greater deployment. Tests of these new technologies in the past 4 years indicate that workable systems can be deployed. These systems have shown the technical capacity to deliver solar heating and desiccant cooling with indirect and direct evaporative cooling. Specifically, these new technologies include the solar thermal tile system shown in Figures 4 and 5 and the NovelAire desiccant evaporative cooling cycle shown schematically, in Figure 6. The solar thermal tile system is a mid temperature air heating collector. It is designed to function as the weather tight roof of a building or as a rack mounted solar collector on low sloped roofs or in ground mounted applications. It is designed to be installed at a cost comparable to high quality slate and tile roofing, which is substantially less expensive than existing mid temperature collectors. As a result, the system can be economically installed to handle the larger space heating loads, even with the seasonal reduction in productivity during the summer months.Stagnation tests show that the systems can achieve internal air temperatures of greater than 200 degrees F (94 C) and more than 130F (72 C) above ambient temperature. An air flow test with an early prototype showed outlet air temperatures of 160 -180 F (71-82 C) are possible. Higher temperatures are expected with optimal orientation, improved materials such as selective surface absorbers, and optimal air flow. The system is of sufficiently low cost to deploy a large area to deliver a large volume of air for winter space heating, and deliver high air outlet temperatures particularly in the summer. This provides an opportunity to support desiccant regeneration with the large quantities of excess summer heat. Because the system is an air heating system, it is well suited for direct delivery of solar heated air for desiccant regeneration.

4.1. Hybrid Desiccant Evaporative Cooling System

There are several ways to integrate the two technologies. One version of the integrated cycle is shown in Figure 7. The cycle shown includes:

1) A solar thermal tile system.
2) A NovelAire desiccant evaporative cooling systems.
3) One additional evaporative cooling system between state points E and F, and
4) A hot water heating system using the waste heat from the desiccant regeneration at state point J.

The psychometrics of the integrated cycle is shown in Figure 8. The increased cooling for the heat exchanger by the building air can be seen from the change in state point temperature from E to F. The first stage cooling of the heat exchanger from A to L can also be seen.The particular integrated cycle shown in Figure 8 does not use recovered heat from the heat exchanger for desiccant regeneration. Instead, the excess solar heated air from the solar thermal tile roof is used as the primary heating source for desiccant regeneration. (An alternative cycle could introduce air from point L into the solar thermal tile roof system.)Supplemental gas heat, as shown in Figure 8, is used to support desiccant regeneration during cloudy days, and possibly early evening cooling hours, or other hours when solar heating is not 100% effective at delivering cool dry air for cooling or dehumidification. With minor adaptation, the supplemental gas heat can also provide the peak space heating required during the coldest winter days.The hot water heating systems uses waste heat from the desiccant regeneration to heat water via an air-to-water heat exchanger. During the rest of the year, solar heated air from the thermal tile roof would be ducted to the same air- to-water heat exchanger for hot water production. Because the solar heating system would provide an air to water heat exchanger for domestic water heating in non summer months, there is little added cost for the heat recovery for water heating. The only added cost would be the duct work and dampers to bypass the desiccant regeneration when cooling is not required.

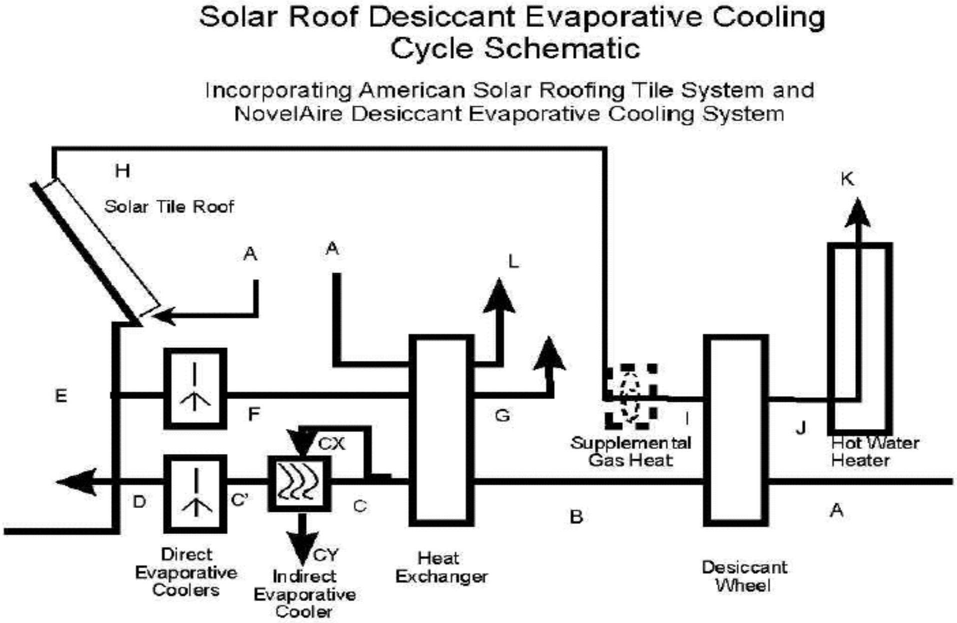

Fig.7: Integrated SOLAR-DES-EVAP cycle

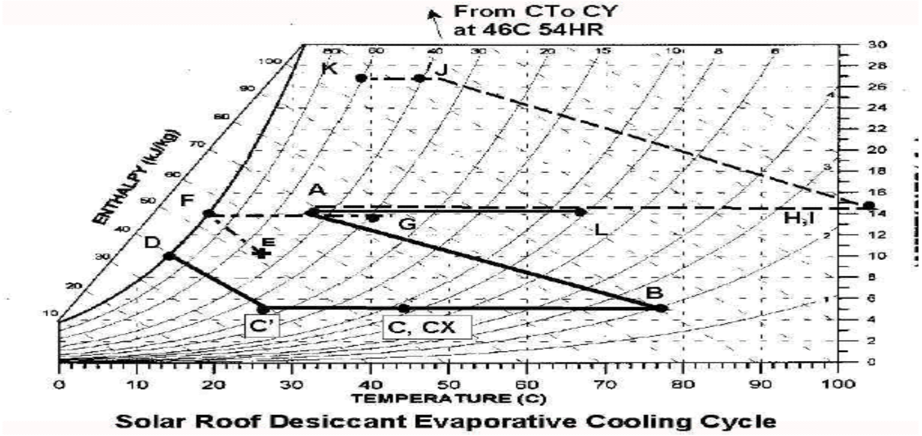

Fig. 8: Integrated SOLAR-DES-EVAP psychometrics

V. PERFORMANCE ANALYSIS

The analysis has been extended to the integrated system and evaluated based on climate conditions for Charlotte, NC. Charlotte has both heating and air conditioning loads. The 600 sq. ft. (56 sq. m.) system would deliver energy cost savings as shown in Figure 9. The total energy savings across the year would be 116 gigajoules (110 million Btu) and only 28 gigajoules (26 million Btu) of fan power would be required. The system would handle 87 % of the annual household heating, cooling, and hot water energy load as derived from EIA data from 1993 (Ref. 4). The system would save $847 per year with gas at $9 per million Btu ($8.86/gigajoule) and electricity at $.0785 per KWHR.In the summer months, the system would handle 100% of the cooling load of the 2000 sq ft. (186 sq. m.) house. These calculations assume a collector efficiency of 35% even during summer cooling with high collector operating temperatures. Fig. 7: Integrated SOLAR-DES-EVAP psychometrics However, if the collector operating temperatures reduce efficiency to only 20%, the system still handles 81% of the seasonal cooling load.

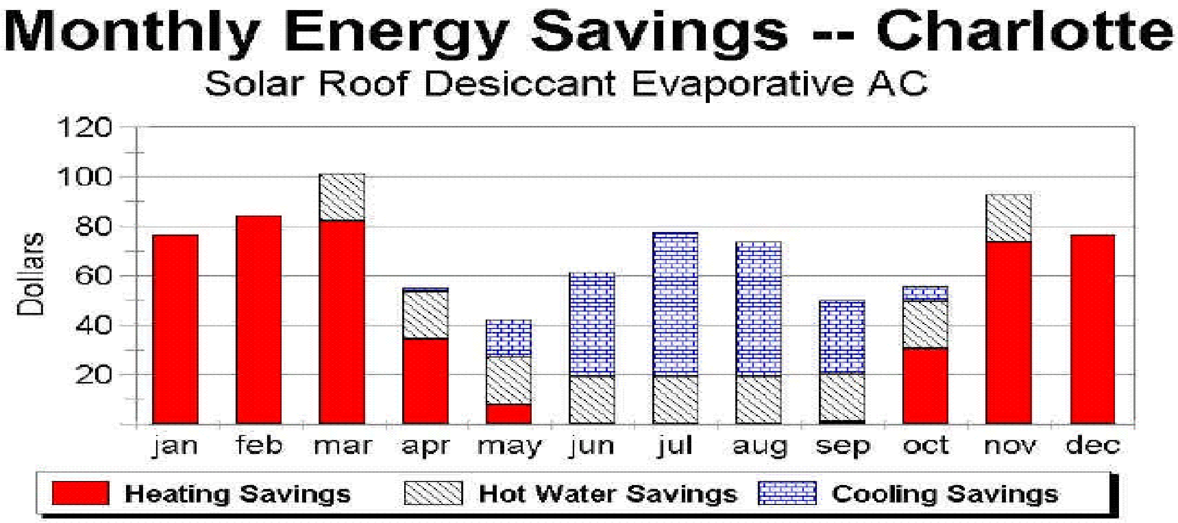

Fig.9: Integrated cycle energy cost saving

VI. ADVANTAGES

(1) Desiccant evaporative cooling, used as stand-alone system or to supplement conventional cooling equipment, removes moisture from the air without the use of ozone-depleting compounds.

(2) Micro organism are well protected indoors by the moisture surrounding them if humidity is above 70% they can cause acute diseases and cause the building structure and it's contain to deteriorate.

(3) Direct indirect and evaporative cooling system is less expensive than vapour compression system.

(4) Hybrid system can provide year round comfort.

(5) It decreases the electrical demand.

(6) Desiccant based system can reduce moisture much below 40f dew point temperature, while the conventional cooling can only dehumidify the air to temperature above 40f dew point temperature.

(7) Desiccant system can often permit reduction in size of the conventional system (vapour compression system), because part of cooling load (dehumidification load) is shifted to desiccant system. Size reduction not only save the energy, but it also decreases the electrical demand and may reduce initial capital investment.

VII. FUTURE SCOPE

Additional research is recommended in the following areas:

1) Evaluate alternative solar tile roof components to establish the most cost effective summer outlet temperature for the solar roof when supporting desiccant regeneration.

2) Prepare a desiccant wheel that is optimized to the outlet temperatures of the solar roof.

3) Assemble the components in an operational prototype and test for cooling performance in a suburban setting.

VIII. CONCLUSION

This study shows that a packaged system with hybrid-desiccant/vapor-compression air conditioning can be a technically feasible alternative to conventional air-conditioning systems. Resource energy savings of 30%-80% can be realized over a wide range of operating conditions, when comparing steady-state performance of the hybrid with conventional systems. These results show promise for developing energy-efficient, airconditioning by extending existing state-of-the-art technology and warrant further research and analysis. Seasonal simulations of the hybrid systems should be undertaken to establish realistic energy savings when operating under variable loads and transient-operating conditions. These system studies should include the simple System 1 studied in this report, where the dehumidifier and vapor-compression subsystems are operated in series, and System **3,** which incorporates the indirect evaporative cooler. This analysis must also include development and evaluation of control strategies for operating the various subsystems together.**A** laboratory experimental program to verify the analysis of the hybrid concept is required The effort should involve industrial participation from manufacturers of dehumidifiers and vapor-compression equipment. The project should confirm the accuracy of the design tools used in this study and should measure system performance under actual operating conditions.

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