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Desiccant Cooling/Dehumidification for Army Facilities

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Desiccant-Based Dehumidification for Army Facilities

by
Gerald L. Cler

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FOREWORD

This research was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC) under project 4A162784AT45, "Energy and Energy Conservation," work unit EB-XT1, "Desiccant Cooling/Dehumidification for Army Facilities." The USAEHSC technical monitor was P. Conner, CEHSC-FU-M.

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1 INTRODUCTION

Background

The U.S. Army maintains over 1 billion square feet (sq ft)* of conditioned space worldwide; approximately 750 million sq ft of this is located within the continental United States (CONUS). These facilities are used for training, housing, storage, medical services, recreation, and many other purposes. The Army also owns more than 600,000 tons of air-conditioning and dehumidifying equipment used to make this space comfortable. Due to increased loads from electronic equipment, higher occupancy levels, and the requirement for greater volumes of outdoor ventilation make-up air, many facilities are not able to maintain the desired occupant comfort level for temperature and humidity. Vapor compression air-conditioning equipment generally is used to control the temperature of the air. Unfortunately, controlling temperature alone does not adequately address the problems of human comfort, air quality, and building maintenance (mildew and moisture damage). Army building managers need to be able to better control the humidity in conditioned space in the most cost-effective manner.

Most Army buildings that have people working in them regularly are air-conditioned to control the space temperature. The accompanying dehumidification often is inadequate, resulting in high relative humidity (RH) levels within the space. In facilities that require humidity control (storage facilities), the proper RH level is obtained by cooling the air below the desired temperature, to condense out more moisture, and then reheating the supply air to the desired temperature before delivering it to the conditioned space. This process is expensive, wastes energy, and requires a chiller much larger than would otherwise be necessary, which increases the initial system cost and the operating cost by increasing the electric demand. In some cases, electric reheat is used, which further increases cost and electric demand.

Many Army facilities are located in the southeastern United States, where summers are hot and very humid, and the RH averages 80 percent. Latent cooling in these areas can exceed 50 percent of the total cooling load. In the spring when little or no sensible cooling is required, excessive humidity levels can make occupants uncomfortable, requiring the air-conditioner to operate solely for dehumidification. With a light cooling load, the chiller will cycle frequently and cool the air to near saturation before it is delivered to the space. This moist air and moist duct liner material can provide an excellent habitat for micro-organisms such as that responsible for Legionella (Legionnaire's Disease).

Outside ventilation air requirements vary depending on the function of the facility and whether or not smoking is allowed. Ventilation air requirements for nonsmoking areas range from 5 to 20 cubic feet per minute (cfm)/person, depending on room activity, and can increase to 50 cfm/person in smoking rooms. Even in relatively mild climates, use of outside ventilation air can add significantly to the cooling and dehumidification load. As a simple method to reduce energy costs, ventilation dampers are often partially or completely closed. While this practice can reduce the energy costs to operate the air-conditioning system, indoor air quality can become a health risk. In some regions of the country, naturally occurring radon can reach levels so high that without proper ventilation, the radon may be a serious health hazard. New materials used in building construction, such as insulation, carpet, and adhesives, along with furniture and other furnishings can contain formaldehydes and other harmful chemicals that are released

*A metric conversion table is on page 22.

into the air. Without proper ventilation these chemicals in the air can lead to "sick building syndrome" and can pose a serious health risk to building occupants.

Increasing occupancy levels also require higher ventilation rates. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has significantly increased the recommended minimum requirements for ventilation air.[1] This increased requirement is partly due to better construction techniques which, because of reduced infiltration, result in the buildup of radon, formaldehyde, and construction materials and adhesives. This increase in outdoor air can add considerably to the load of a possibly overburdened cooling system.

As construction standards for new buildings become more strict, more attention must be paid to proper ventilation. As ventilation rates increase, the potential savings from better quality construction techniques will decrease unless cost-effective methods of sensible and latent energy recovery are used. Many methods of sensible heat recovery have been developed and have high heat recovery efficiencies. Recently, many new developments with desiccant-based dehumidification equipment have improved the economics of this technology to the point where it is often first-cost competitive in new construction and, because of its reduced operating cost, can have a short payback period for retrofit applications. Hybrid systems containing vapor compression (VC) cooling and desiccant dehumidification are gaining popularity in many new and retrofit applications.

The destruction of the earth's ozone layer by chlorofluorocarbons (CFCs) used in cooling systems has received the attention of the heating, ventilation, and air-conditioning (HVAC) manufacturing industry and political leaders around the world. The production and use of some of the most efficient CFCs will be discontinued or severely restricted in the very near future. The current replacements for CFCs generally are more expensive, reduce the rated capacity of installed equipment, and require more energy for the same cooling effect. While much time and money are being spent on these problems, it will take many years to define the best CFC options.

Fortunately, the outlook is not as bleak as it may seem. New refrigerants are being developed with improved performance, higher efficiency lighting and electronic equipment reduces both their operating costs and their contribution to the cooling load, and improvements in HVAC equipment have made it possible to maintain the required outdoor air ventilation rates without an excessive energy penalty.

New desiccants being developed improve system efficiency, reduce equipment size, and lower the temperature requirements for desiccant regeneration, thus what was once low temperature reject heat can now be considered useful energy. New thermodynamic operating cycles are also being developed to improve system performance and reduce equipment size and weight.

Space dehumidification and enthalpy (heat and moisture) recovery in the ventilation air stream can significantly reduce peak electric demand for air-conditioning and reduce the overall cost of operating a building's HVAC system. Desiccant-based dehumidification is one option that can help Army building managers achieve cost-effective space conditioning.

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[1] *ASHRAE Handbook, 1989 Fundamentals* (American Society of Heating, Refrigeration, and Air Conditioning Engineers [ASHRAE], 1989).

case studies, and (3) describe the advantages of desiccant-based equipment for humidity control in HVAC applications from both an energy and economic standpoint.

Approach

Researchers identified the currently available desiccant equipment capable of meeting the Army's requirements for humidity control within a conditioned space and obtained performance characteristics for this equipment. A computer program (DOE-2; see Appendix A for a list of simulation programs) was used to simulate a generic office building at six different locations (climates) throughout the United States. The program compared using a vapor compression chiller and a desiccant dehumidifier for preprocessing ventilation make-up air for the building. Electric demand reduction and electric and gas energy consumption were then compared. The operating costs of each of these systems were then compared. Simple payback periods for the desiccant dehumidification system were then determined based on an estimate of equipment costs and the energy savings as determined from the simulations for each location.

Scope

This report documents the results of an energy simulation of an office building at six different locations (climates), using the local gas and electric utility rates, and is therefore not all encompassing.

Mode of Technology Transfer

It is recommended that the information in this report be summarized in a Technical Note (TN) on alternative methods for building dehumidification and energy recovery. At this time of concern over rising energy costs, indoor air quality, and CFC bans and replacements, this TN would serve as a means of introducing the desiccant technology to field personnel. It is also recommended that this information be included in revisions to Technical Manuals and Corps of Engineers Guide Specifications for HVAC systems, and be incorporated into a PROSPECT training course.

2 ARMY BUILDING STOCK

Table 1 lists the U.S. Army's building stock in the continental United States. Family and bachelor housing comprises the largest area of Army building space. The desired indoor RH is usually between 40 percent and 50 percent. With many of the Army facilities in the southeast, dehumidification can be a significant part of the cooling load. And because typical air-conditioning control is based on temperature alone, humidity levels are often much higher than 50 percent. High humidity levels in houses and apartments increase maintenance costs due to moisture damage and can provide an excellent climate for mildew growth. Desiccant-based cooling and dehumidification equipment is available for residential applications. Equipment is also available from several manufacturers for larger applications (Appendix B).

Storage is the second largest category of Army building space. Not all of this space is humidity controlled but some requires an RH of 40 percent. Where humidity control is required, VC equipment is often used. In storage facilities, the load is nearly all latent, making it an ideal application for desiccant equipment. Where desiccant equipment is used, electric regeneration is often used; heat recovery is not. Both of these methods raise the operating costs. Heat exchangers for this purpose are offered by several desiccant equipment manufactures who claim a 1-year payback due to energy savings. Fuel type (gas or electric regeneration) and heat recovery should be carefully considered when selecting equipment.

Hospitals and medical facilities require high outdoor air ventilation rates; some areas within hospitals require 100 percent ventilation air. This requirement, along with the requirement for continuous operation, makes hospitals one of the most energy intensive buildings in common use. Hospital requirements for RH vary from 30 to 95 percent and as many as 15 changes of outdoor air per hour. New hospitals often

Table 1

U.S. Army CONUS Building Stock

Type	Area*	Percent
Family housing	156,767	21
Storage	156,097	21
Bachelor housing	126,022	17
Maintenance and Production	76,193	10
Training	56,451	8
Community	51,147	7
Administration	49,147	7
Operational buildings	30,347	4
Hospital and medical	21,484	3
Research, development, and testing	13,533	2
TOTAL	737,990	

*Square feet, in thousands.

use heat recovery systems but, in general, dehumidification is accomplished by overcooling the air and, after dehumidification, reheating the air to the desired temperature. Again, this is a wasteful and very expensive operating practice.

Other building types have RH and outdoor ventilation rates that vary with building use but typically are within 40 to 50 percent RH and ventilation with outdoor air about 5 cfm per person. Training, administration, and community areas should be within this range. Areas such as libraries and museums often require somewhat lower RH and ventilation rates. The RH in swimming pool areas can be higher but should never be high enough to allow condensation an walls or other surfaces as this can cause extensive damage to these surfaces and the building structure and can create an ideal place for mildew to grow. Maintenance and production areas require special consideration for outdoor ventilation air, depending on the activity taking place within the facility, and should be investigated individually.

Dehumidification in an occupied space can account for one-third of the total air-conditioning load. When high ventilation air flow rates are required, equipment capacity can be double that required for the actual space load. Energy costs can also increase when the supply air stream must be reheated after it was overcooled in order to condense moisture on the cooling coil surface. Not only do the cooling and reheat processes require more energy, but also the fan power requirements increase as more moisture is condensed on the cooling coil. Desiccants, or drying agents, can play a vital role in reducing the cost of conditioning occupied spaces.

3 DESICCANTS AND THE DEHUMIDIFICATION PROCESS

Proper control of temperature and relative humidity can reduce building operating costs while improving the occupants' comfort. The use of desiccant-based dehumidification along with a vapor compression chiller allows independent control of these two factors. Recovery of both sensible and latent energy in the chiller's exhaust air can play a major role in keeping energy requirements at the lowest possible level. Desiccant materials and generic dehumidification cycles are described in the following sections.

Desiccant Materials

Virtually all materials absorb water vapor. Desiccants are materials that can remove a relatively large amount of moisture. Desiccant materials can be either solid or liquid. While both types work equally well in most applications and have about equal energy efficiencies, special cases exist where one may be more appropriate than the other due to space limitations or construction constraints.

Industry research continues to improve these materials by increasing their moisture removal rates. This results in smaller equipment, lower regeneration temperatures, and, consequently, reduced energy requirements. New materials are being developed that meet the general requirements of the HVAC industry. Both liquid and solid desiccants also can remove bacteria from the air stream being processed. This factor is especially important to hospitals and laboratories.

Solid Desiccants

Solid desiccants can be either adsorbents or absorbents. Adsorbents, such as silica gel and activated alumina, undergo no chemical or physical change during the moisture removal process but hold a large amount of moisture on their particle surfaces. Absorbents, such as lithium chloride (LiCl), do change chemically and/or physically while picking up moisture. Selection of one desiccant over another depends on the environment being conditioned. A dew point temperature (T_{DP}) below 0 °F is easily obtained and a T_{DP} less than -40 °F is possible. Typical regeneration temperatures for solid desiccants are between 125 and 300 °F, depending on the desiccant material and how it is being used. These relatively low temperatures add flexibility when selecting a source of regeneration energy. Solid desiccants are usually held in a packed tower, rotary bed, or a rotary wheel.

Liquid Desiccants

Liquid desiccants are absorbents; they physically and/or chemically change as they pick up water. Triethylene glycol is a common liquid desiccant. Typically, liquid desiccants have a minimum T_{DP} of about 10 °F. Attempts to reduce T_{DP} below this temperature require excessively high regeneration temperatures and can result in the desiccant crystallizing on the heating elements. Liquid desiccants generally are sprayed into the air stream from the top of the conditioner or regenerator. Air flow can be either counter to or parallel with the flow of desiccant. A particular advantage of a liquid desiccant is the ability to locate the regenerator remote from one or more conditioners.

The Desiccant Dehumidification Process

Although solid and liquid desiccants are used in different types of equipment, the dehumidification process is similar. For ease of explanation, the following discussion focuses on solid desiccant equipment.

Recirculation Mode

In the recirculation mode, return air from a facility passes through the desiccant dehumidification equipment for moisture removal and then, if required, is sensibly cooled with vapor compression equipment before being returned to the supply air handling equipment. Figures 1 and 2 show a typical solid desiccant system operating in the recirculation mode and the psychrometric chart, respectively.

Return air from the conditioned space first passes through a slowly rotating desiccant matrix. This hot, dry air stream is then sensibly cooled with a heat recovery heat exchanger and an indirect evaporative cooler before being returned to the conditioned space. The regeneration air stream, ambient air in this case, is directly or indirectly evaporatively cooled before passing through the heat recovery heat exchanger where it recovers sensible heat while cooling the process air stream. This air stream is further heated and as it passes through the desiccant wheel, drives off moisture and is rejected to the atmosphere. In a humid climate, this process generally is the most efficient for maintaining low relative humidities, although it does not allow for building ventilation.

Ventilation Mode

As the name implies, the ventilation mode processes ambient air to be delivered to the conditioned space. In this mode, the exhaust air from the facility is often used in the regeneration air stream. If contamination of the incoming air is possible, the exhaust air would be rejected and ambient air would be used for regeneration. This cycle generally is less efficient than the recirculation mode, but can allow for a large amount of make-up air to be dehumidified before entering the sensible cooling coil. This process commonly would be used in hospitals or laboratories where a high percentage of make-up air must be used. Figures 3 and 4 show a typical solid desiccant system operating in the ventilation mode and the psychrometric chart, respectively.

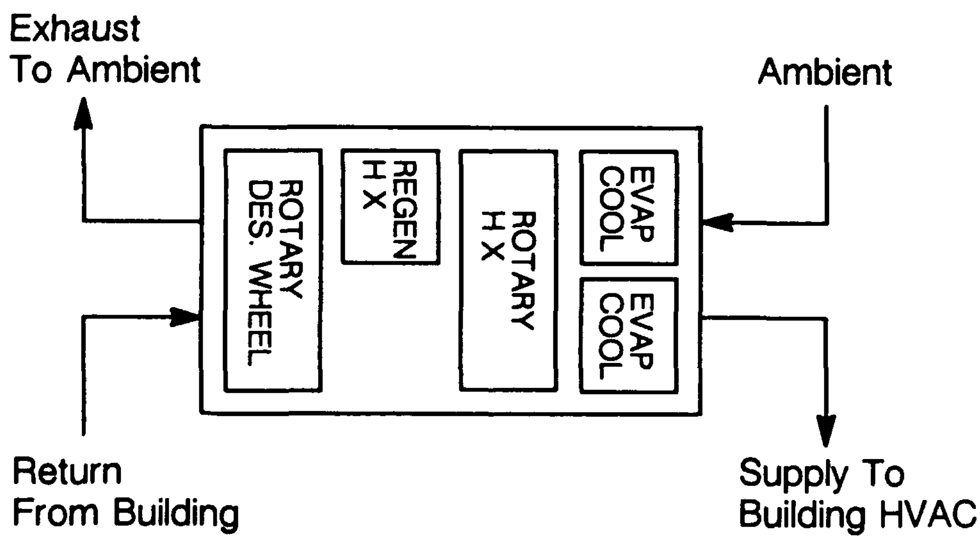

Figure 1. Recirculation Mode Process.

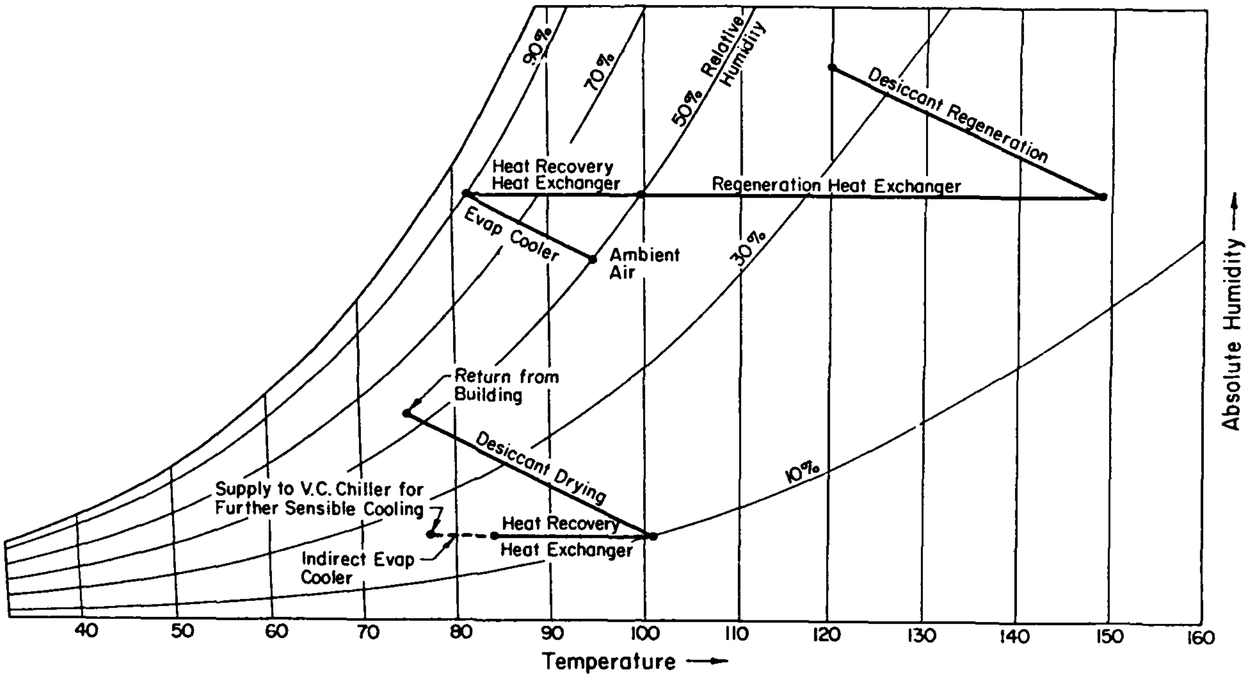

Figure 2. Recirculation Mode Psychrometric Chart.

Ambient air first passes through a slowly rotating desiccant matrix. This hot, dry air stream is then sensibly cooled with a heat recovery heat exchanger and an indirect evaporative cooler before entering the supply air stream where it can be further sensibly cooled, if required, with vapor compression equipment. The regeneration process uses the return air from the conditioned space. It is directly or indirectly evaporatively cooled and then heat is removed in the heat recovery heat exchanger. It is then further heated to the required temperature in the regeneration heat exchanger before passing through the desiccant wheel, driving off the absorbed moisture. This air is then rejected to the atmosphere.

Enthalpy Recovery

Enthalpy recovery is similar to the ventilation mode in that no regeneration energy is supplied other than the energy in the exhaust air. As the exhaust air leaves the building, it comes in contact with the desiccant material, typically in a rotating wheel placed between the supply and exhaust air streams. Figures 5 and 6 show a typical system operating in the enthalpy recovery mode and the psychrometric chart, respectively. The exhaust air stream, being relatively cool and dry (compared to the outdoor air) cools the desiccant and picks up some of the moisture it is holding before exiting. As a portion of the desiccant wheel comes in contact with the incoming, ambient make-up air, it is able to cool the air and remove some of its moisture. If desired, an indirect evaporative cooler can be used with this process to precool the exhaust air before it enters the enthalpy wheel.

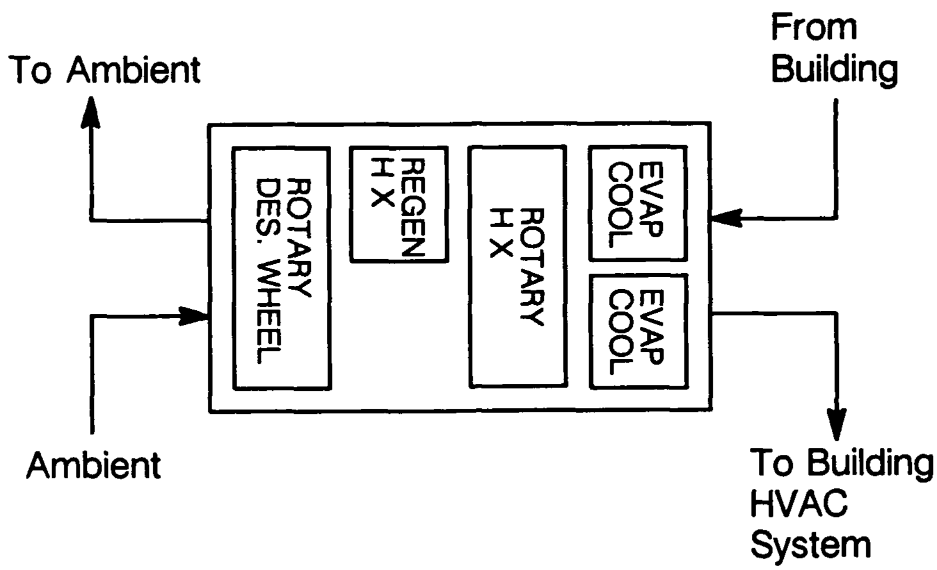

Figure 3. Ventilation Mode Process.

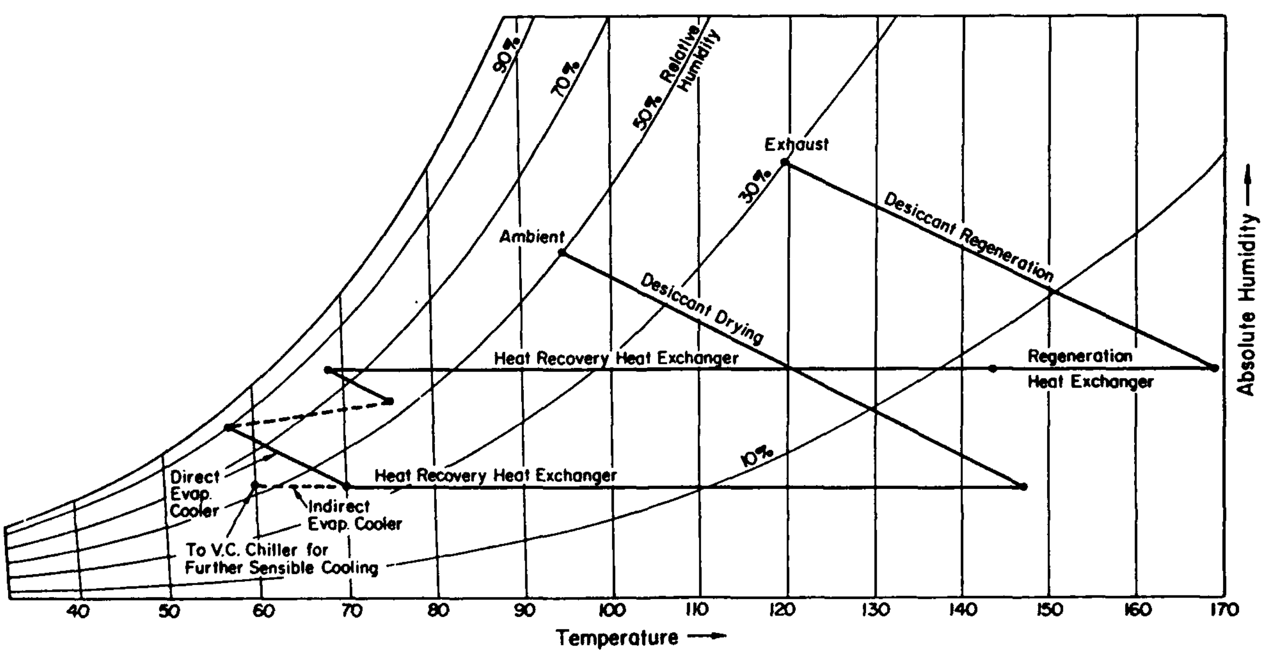

Figure 4. Ventilation Mode Psychrometric Chart.

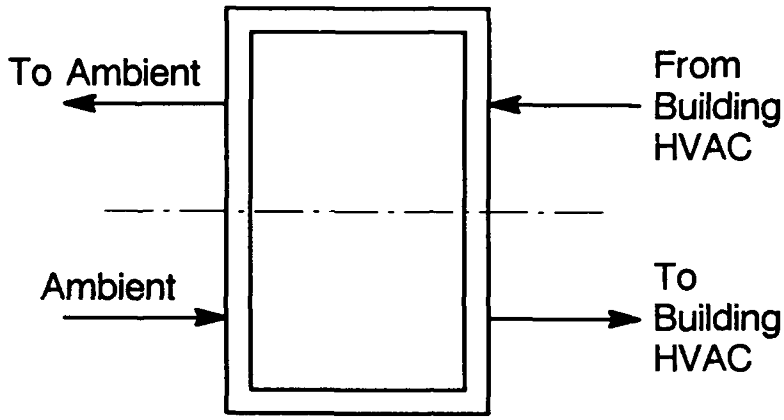

Figure 5. Enthalpy Recovery Process.

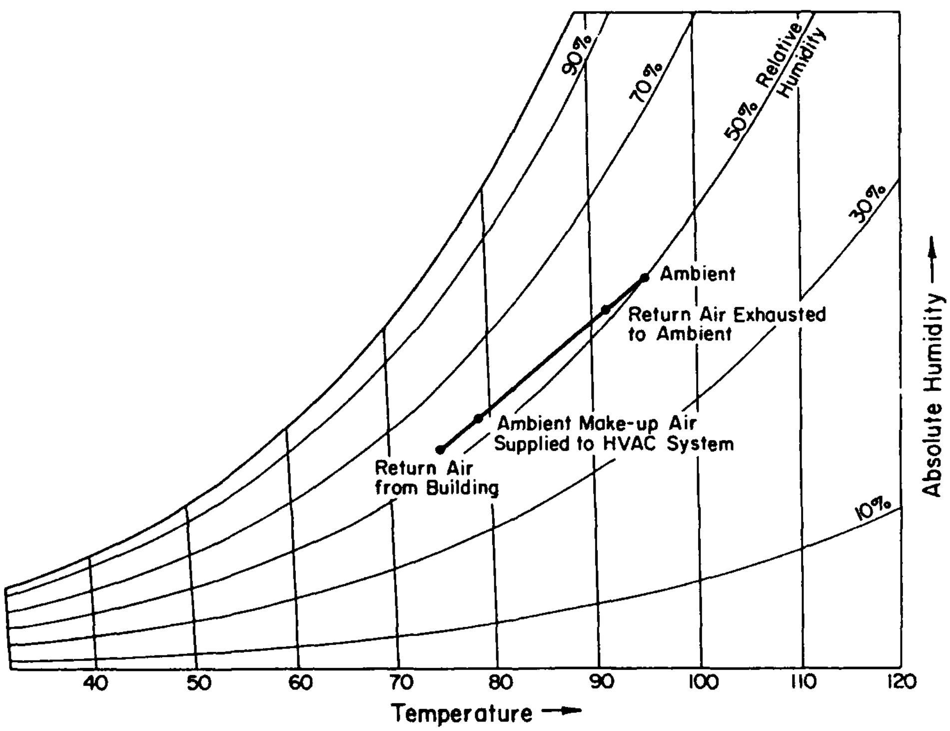

Figure 6. Enthalpy Recovery Psychrometric Chart.

Regeneration Energy Options

A number of options are available for regeneration energy. The simplest would be a complete packaged desiccant dehumidification system that includes a small packaged boiler, controls, regeneration heat exchanger, and connections. While this may be the simplest option when considering initial installation, it may not make use of other energy sources, which could help reduce operating costs. Most desiccant manufacturers can provide equipment for use with a variety of regeneration options. Hot water, steam, and hot gas air-to-air heat exchangers are the most common methods of desiccant regeneration in HVAC applications. The purchaser should specify the appropriate heat exchanger type when the system is ordered. Although several special applications use electric resistance heat, this option is recommended only in a few special applications (such as shops where the flame from a gas regeneration unit would be dangerous because of the possibility of igniting organic fumes in the air) and generally should not be considered practical because of the high cost of electricity.

Vapor Compression Desuperheat

Vapor compression (VC) chillers must reject the heat removed by the evaporator through the condenser. The superheat available in this process can supply a significant fraction of the regeneration energy requirements. Incorporating this option relies heavily on the physical location of the equipment. To take full advantage of the available desuperheat, the chiller must be located near the desiccant equipment. A desuperheat heat exchanger is inserted in the refrigerant line between the compressor and the condenser. Energy is removed from the refrigerant by heating the desiccant regeneration air stream. The thermal energy removed in this process is then diverted from the chiller cooling tower, reducing its overall load.

Cogeneration

The thermal energy available from a cogeneration system can be used for heating service hot water or for space heating during the winter. Unfortunately, the space heating requirement is not uniform throughout the year and the service hot water load may not be large enough to use all the heat available from the cogeneration plant. During the summer when heating loads are low and air-conditioning loads are high, this energy can be used to regenerate the desiccant. Hot water and/or the exhaust gas from an internal combustion engine is directed to the desiccant regeneration air stream to dry the desiccant. This can be a very cost effective method of using the cogenerated heat and electricity because the peak electric demand usually occurs during the air-conditioning season. Electricity produced during this period reduces the demand. The desiccant equipment can also reduce the demand by removing part of the cooling load from the electric chiller. There is also very good coincidence between the available thermal energy and the dehumidification requirements. Several manufacturers provide preengineered cogeneration/desiccant dehumidification systems, which can also provide service hot water as desired.

Solar Energy

Another option receiving attention is the use of solar energy for desiccant regeneration. Using solar collectors during the summer, as well as in the winter for space heating, can dramatically improve the economy of the solar system. Although solar collectors can provide the high temperatures required to drive an absorption chiller, the system efficiency at these temperatures can be very poor, particularly if the collectors are flat plate. The temperatures required for desiccant regeneration typically are much lower and the system operation is not as temperature dependent as for absorption chillers. At low regeneration temperatures (100 to 125 °F) the rate of moisture removal decreases but does not stop. It is possible to use solar energy to preheat the regeneration air stream with a natural gas fired heater (other fuel source), to supply regeneration air at the temperature needed to dry the desiccant.

Existing Boilers

It is also possible to use an existing boiler for desiccant regeneration if the boiler must remain in service throughout the year, even though the summer load is small. Increasing the summer load on such a boiler would generally tend to improve its operating efficiency and would spread the overhead cost of keeping the system hot over a larger load, thus reducing the operating cost per unit of thermal energy required. (Note: the heating manager should determine if this boiler is really needed, or if a small water heater at the load would be more appropriate, allowing the larger boiler to be shut down in the summer. If the boiler must operate, this steam or hot water source can very effectively be used for desiccant regeneration.)

Desiccant-based cooling and dehumidification equipment has many advantages over VC equipment. It allows higher outdoor air ventilation rates, which can significantly improve indoor air quality and reduce potential health risks associated with tightly sealed buildings. Desiccant-based equipment does not require CFCs.

Hybrid Systems

Hybrid systems offer unique advantages over individual desiccant or VC systems. In these systems, part of the VC condenser heat that would otherwise be rejected directly to the atmosphere can be used to regenerate the desiccant material. This can substantially reduce the operating cost of the cooling system. Natural gas can be used, as required, to complete the regeneration process. By shifting part or all of the cooling load from electricity to natural gas, the electric demand for air-conditioning can be reduced. This results in lower electric utility charges. Maintenance and repair costs for desiccant-based equipment generally are lower than for VC equipment because desiccant equipment has few moving parts. These parts (fans, blowers, heat exchangers) are easily repaired and do not require highly trained, technical maintenance personnel. The cost of refrigerants for VC cooling equipment is also expected to increase sharply as more restrictions are placed on CFCs. Desiccant compounds are generally safe, nontoxic materials.

4 BUILDING SIMULATION

Building Location

Researchers used the DOE-2, Version 2.1E computer program to simulate energy consumption for a typical administration building at six different locations representing a variety of climates in the United States. The locations and their 1 percent design conditions are listed in Table 2. This data is also plotted on a psychrometric chart in Figure 7. The locations were selected to compare the performance of a generic desiccant system to a vapor compression system.

Building Description

The administration building considered is a 49,000 sq ft, three-story structure. Approximately one-third of the exterior wall area is glazed. The occupancy schedule is 515 people 5 days per week and one-half day on Saturdays; the office is closed on Sundays. The HVAC system has variable air volume air handling units serving each floor. A direct expansion, air-cooled condenser is used for the main cooling system. The system capacity is varied as required at each geographic location. The HVAC system was designed to include a separate system to precondition the ventilation air supplied to the building at a rate of 20 cfm/person (10,000 cfm total). The options considered for preconditioning the air are a direct expansion, vapor compression rooftop outside air-conditioning system and a desiccant dehumidification system. Each system processes 100 percent of the ventilation air stream but none of the return air stream. This allows for the most cost effective use of the system for preconditioning the ventilation air.

Although administration buildings represent only 7 percent of Army building stock, researchers selected this type of building because of the wider range of cooling demand (due to equipment use and occupancy) and the predicability of the use patterns.

Table 2

Design Cities and Conditions

City	Design Temperatures (°F) Dry Bulb	Wet Bulb
Atlanta, GA	92	77
Chicago, IL	94	79
Houston, TX	97	80
New York, NY	89	76
San Diego, CA	83	71
Washington, DC	93	78

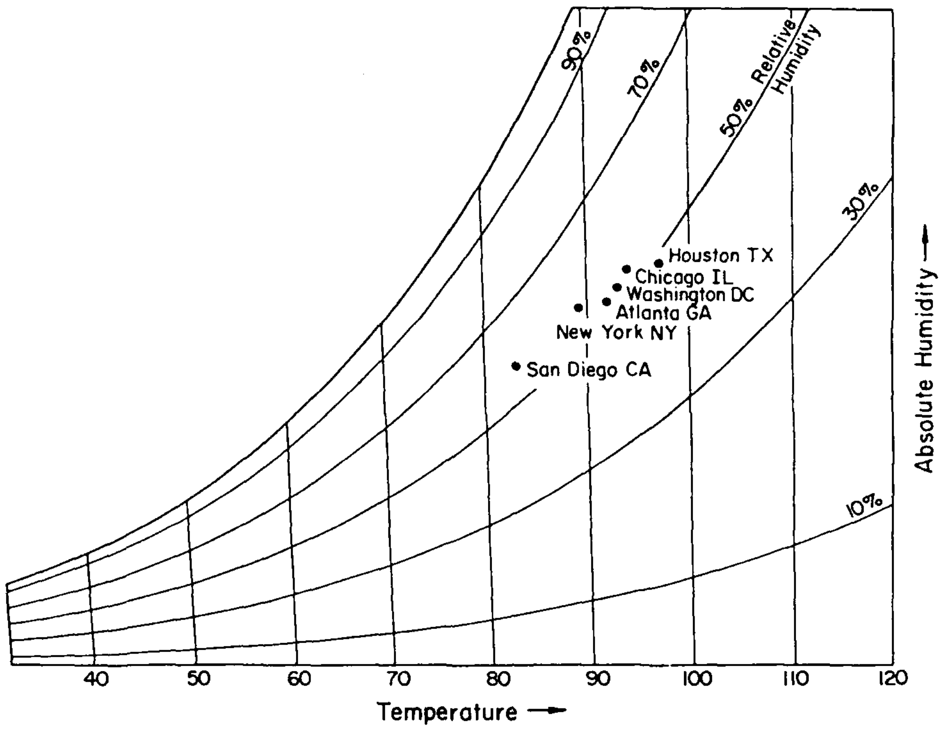

Figure 7. Psychrometric Chart.

Electric and Gas Utility Rates

Researchers used the local electric and natural gas utilities rates to perform an economic analysis and compare the cost effectiveness of owning and operating a desiccant-based dehumidification system as opposed to a typical vapor compression cooling system. These rate schedules are for a large energy user such as an Army facility. The energy costs used in the analysis are for the least expensive energy, as that would be the electricity displaced if a desiccant system were to be used instead of a vapor compression system. The same is true for the price of natural gas. Any incremental increase in gas consumption would be at the lowest rate. The utility rates used are listed in Appendix C.

System Performance

The energy consumption and operating costs of the two options are compared in the following paragraphs. The application is a retrofit to increase cooling capacity in situations where the existing cooling system capacity is at the upper limit. For this analysis, one cost estimate is used. It is expected that variations will be minor since the required air flow for each location is the same, particularly for the desiccant system as the initial cost is typically a function of air flow rates (the operating cost is a function of climatic conditions). A simple payback analysis is also performed to determine the cost effectiveness of these systems.

Base Case - Preconditioning With VC Chiller

To precondition the ventilation air before it is mixed with the return air, the make-up air handling unit is equipped with a direct expansion, vapor compression chiller. This chiller is designed to deliver ventilation air to the HVAC system at 65 °F throughout the cooling season. This air is then mixed with the building return air and cooled to the supply air delivery temperature of 55 °F. The electrically driven chiller in this system can add significantly to the electric demand of the building. A cost estimate for this example system was developed to compare it to the desiccant alternative. Adding a chiller to an existing system is expected to cost about $62,300 (including all duct, electrical, and mechanical work).

Alternative - Preconditioning With Desiccants

This alternative for increasing the cooling capacity used a natural gas regenerated desiccant-based dehumidification system to substantially reduce the humidity level of the ventilation air before it is mixed with the building return air stream. Using a thermally driven system (natural gas fired) instead of an electrically driven system, avoids a significant increase in electric demand. The desiccant system is designed to deliver ventilation air to the return air stream at a constant dew point temperature of 50 °F throughout the cooling season. This can substantially reduce the latent load on the HVAC system cooling coil, resulting in better control of both temperature and humidity. Adding the desiccant dehumidification system to the ventilation air system is expected to cost about $65,600 (including all duct, gas piping, electrical, and mechanical work).

Table 3 lists the electric energy, demand, and natural gas consumption of the desiccant system. Table 4 lists the operating costs. It can be seen in Table 3 that electric energy and demand are reduced in all cases for the desiccant system while gas consumption increases. This is because of the high electric consumption (low Energy Efficiency Ratio [EER]) of the vapor compression system, which uses no gas, compared to the low electric consumption of the desiccant system. Since the desiccant system is thermally driven, the regeneration process requires natural gas, or some other thermal energy source, thus increasing the gas consumption. This indicates the relative benefit of a desiccant dehumidification system for areas with high electric energy and demand charges and low gas prices.

Table 3

Energy Savings and Use for a Desiccant Dehumidification System*

City	Electricity Savings (kWh)	Demand Savings (kW)	Increase in Gas Use (MBtu)
Atlanta	98,800	72	1310
Chicago	74,200	55	700
Houston	151,300	62	2460
New York	72,000	51	660
San Diego	72,700	41	610
Washington	84,100	59	960

*Quantities are differences.
Savings = VC system - Desiccant system

Table 4

Cost Savings for a Desiccant Dehumidification System

City	Electricity Savings ($)	Additional Gas Cost ($)	Annual Savings ($)	Simple Payback (in months)
Atlanta	9,000	3,300	5,700	7
Chicago	8,300	2,100	6,200	6
Houston	6,300	8,200	-1,900	-
New York	7,600	4,400	3,200	13
San Diego	8,700	2,500	6,200	6
Washington	8,900	3,000	5,900	7

The economic benefits of using a desiccant cooling system over a vapor compression chiller must be carefully analyzed. The climatic conditions and make-up air requirements determine the energy benefits of using a desiccant-based dehumidification system. The relative cost of the different energy sources determine the economic benefits of selecting one system over the other.

In this analysis, Houston does not have a positive annual cash flow because of the relative difference in the costs of electric energy, electric demand, and the cost of natural gas. The price of natural gas in Houston is very close to the average cost of gas in the other cities considered, but the price of electricity is the lowest. This reduces the potential benefits of any fuel switching technology.

It should be noted that the results for Houston do not reflect poor system performance in hot, humid climates. Desiccant-based systems work extremely well in these conditions. It just happens that Houston has relatively low electric costs and, as a result, desiccant dehumidification may be an inappropriate technology for this economic region, not the climatic region. As with any of the locations considered, if a source of thermal energy is available (e.g., latent heat rejected to the air), and this source can be used to regenerate the desiccant, even partially, the economic benefits of the desiccant system will improve.

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Desiccants, or drying agents, can be either liquid or solid. Liquid desiccants are sprayed into the conditioned air stream. A particular advantage of liquid desiccants is that the regenerator can be located away from the conditioner. Solid desiccants are usually held in a packed tower, rotary bed, or rotary wheel that is placed in the return air stream or outside make-up air stream. Exhaust air is used to regenerate the desiccant.

The recirculation operating mode dehumidifies the return air, which is cooled with VC equipment before being returned to the supply air stream. In a humid climate, this mode generally is the most efficient for maintaining low relative humidities, although it does not allow for building ventilation. The ventilation operating mode dehumidifies outside air, which is cooled with a heat recovery exchanger and an indirect evaporative cooler before entering the supply air stream. This mode would be used in hospitals or laboratories where a high percentage of make-up air must be used. The enthalpy recovery operating mode uses exhaust air to cool and dry (regenerate) the desiccant before the air exits the system. The desiccant typically is held in a wheel that also provides dehumidification for the make-up air. Hot water, steam, and hot gas air-to-air heat exchangers are the most common methods of desiccant regeneration in HVAC applications.

The office building simulated for the evaluation of energy consumption and operating cost used a direct expansion, air-cooled condenser as the main cooling system. The ventilation air stream of approximately 10,000 cfm was preconditioned using either another, smaller direct expansion chiller or a desiccant-based dehumidification system. Adding the second chiller to the system is expected to cost about $62,300 (including all duct, electrical, and mechanical work). Adding a desiccant system is expected to cost about $65,000.

A number of options are available for regenerating moisture-laden desiccant. Systems available from manufacturers include hot water, steam, air-to-air heat exchange with hot gas, and electric resistance. The purchaser must specify the appropriate heat exchanger type when the system is ordered. Thermal energy sources include steam or hot water boilers, desuperheat energy recovery from vapor compression chillers, heat recovery from cogeneration projects, and solar energy.

Conclusions

A desiccant-based system can be a very cost effective method of dehumidifying building ventilation air streams. In the administrative building simulation, electric energy and demand charges were reduced in all cases for the desiccant system while gas consumption increased. This indicated the relative benefit of a desiccant system for use in areas with high electric energy and demand charges, but low gas prices. The annual savings of the desiccant system over the chiller system ranged from $3200 to $6200, with payback periods ranging from 6 to 13 months.

The simulated system in Houston, TX provided the one exception to the positive results. Although the price of natural gas in Houston is similar to the price in other cities, the price of electricity is low. Since a typical desiccant system will reduce electricity charges and increase gas charges, the energy costs in Houston resulted in increased total costs and a negative annual savings. This example shows that any fuel switching technology should be carefully considered based on the local cost of various energy sources.

Desiccant dehumidification systems become particularly economical when waste heat recovery is possible.

Recommendations

Based on the results of this study, it is recommended that when additional cooling capacity is required in existing HVAC systems, desiccant dehumidification systems be considered as a possible option. As indoor air quality issues (naturally occurring radon and chemicals used in construction) require greater quantities of outdoor make-up air, existing chiller capacity may be insufficient to meet the increased cooling demand. Desiccant-based systems are ideal for this type of application.

In new construction, desiccant dehumidification equipment should be considered for processing ventilation air and removing a portion of the latent load from the cooling coil. This can reduce the size of the installed chiller and can reduce the electric demand of the facility during the summer when the peak electric demand is typically set. Depending on the electric utility rate structure, this can reduce the electric bill for every month if there is a high ratchet clause on the peak demand.

When a desiccant system is designed into a building instead of being added onto it, it is possible to reduce costs further by considering options for desiccant regeneration, including vapor compression desuperheat recovery, solar energy, cogeneration heat recovery, and others. These options should also be considered early in the design stage.

METRIC CONVERSION TABLE

1 lb/hr	=	0.126 g/s
1 cu ft	=	0.028 m^3
1 sq ft	=	0.093 m^2
0.55(°F-32)	=	°C

APPENDIX A: Analysis Tools for Evaluating Desiccant Dehumidification Systems

Most, if not all, manufacturers can provide computer simulations that evaluate their desiccant dehumidification equipment. However, it is unlikely that they are willing or able to evaluate an entire building HVAC system. It is more likely that they will perform an analysis that will indicate the economic benefits of their equipment compared to the "standard way of doing business." While this information is useful, it is often insufficient for the designer who is trying to optimize all components of an HVAC system. The following computer building simulation codes allow for evaluating desiccant dehumidification equipment.

BLAST-Building Loads and System Thermodynamics

Information is available from the BLAST Support Office at:

University of Illinois at Urbana-Champaign
BLAST Support Office
30 Mechanical Engineering Building
1206 W. Green Street
Urbana, IL 61801

Telephone: (800) UI-BLAST / (217) 333-3977
FAX: (217) 244-6534
e-mail: support@uiucbso.me.uiuc.edu

DOE-2 Version 2.1E

DOE-2 information is available from:

National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (703)487-4650

For technical information concerning DOE-2, contact:

Building Energy Simulation Group
Applied Sciences Division
Lawrence Berkeley Laboratory
Berkeley, CA 94720

Telephone: (510) 486-4000

TRACE ULTRA

Information available from:

The Trane Company
Customer Direct Service
3600 Pammel Creek Road
La Crosse, WI 54601-7599

Telephone: (608) 787-3926

TRNSYS - A Transient Simulation Program

Information available from:

Solar Energy Laboratory
University of Wisconsin-Madison
Madison, WI 53711

Telephone: (608) 263-1586

APPENDIX B: Desiccant Equipment Manufacturers

While this is not necessarily meant to be an all inclusive listing of desiccant equipment manufacturers, it is presented here to aid the reader in obtaining information about the different technologies available to them.

Air Enterprises
735 Glaser Parkway, Akron, OH 44306 (216) 794-9770

The Thermal MEC dehumidification equipment manufactured by Air Enterprises contains a solid desiccant impregnated rotary wheel. The system configuration consists of rotary desiccant and heat exchange wheels with the axis of rotation parallel to the air streams, regeneration heat exchanger, and evaporative coolers for both the reactivation and supply air streams. The system also allows for an additional heat exchanger for preheating the regeneration air stream using solar energy or waste heat.

ASK Corp
700 West Loop 340, P.O. Box 2512, Waco, TX 76702-2512 (817) 776-3860

The Energymaster dehumidification equipment manufactured by ASK Corp contains a solid desiccant impregnated rotary wheel. The system configuration consists of rotary desiccant and heat exchange wheels with the axis of rotation parallel to the air streams, regeneration heat exchanger, and evaporative coolers for the reactivation and supply air streams. Systems are available to use natural gas or propane. Completely engineered hybrid systems are also available using waste heat from a cogeneration system for desiccant regeneration. System capacity of up to 6 tons are available with moisture removal rates of up to 37 pounds per hour.

Bry-Air Systems
P.O. Box 269, Rt. 37 West, Sunbury, OH 43074 (614) 965-2974

The Bry-Air dehumidifier consists of a carrousel of vertical beds of solid desiccant material rotating about its vertical axis. The air to be dried enters at the top, center of the carrousel and as it passes through the desiccant material it is dried. This arrangement of vertical beds of desiccant material allows for a portion of the bed to be in the regeneration air stream at all times. Regeneration is accomplished via electric, steam, or gas energy sources. System capacities are available from 500 to 25,000 cfm and moisture removal rates of 16.8 to 839 pounds per hour.

Cargocaire Engineering Corp.
79 Monroe Street, P.O. Box 640, Amesbury, MA 01913-4740 (508) 388-0600

Cargocaire manufactures a wide range of dehumidification equipment, all of which is based on a solid desiccant impregnated wheel rotating about an axis parallel to the air stream flow. The systems consist of desiccant wheels, regeneration heat exchangers, and reactivation heat recovery heat exchangers. Components can be configured as a complete integrated dehumidification system for maintaining temperature and humidity. Equipment capacities range from 50 to 40,000 cfm and moisture removal rates of 0.6 to 2000 pounds of water per hour.

Dryomatic Division of Airflow Company
295 Bailes Lane, Frederick, MD 21701 (301) 695-6500

Dryomatic equipment consists of a single continuously rotating cylinder of desiccant material. The air to be dried enters the chamber surrounding the desiccant cylinder and then passes through the sides of the hollow cylinder and exits through the center. A portion of the cylinder is partitioned off for desiccant regeneration. This can be accomplished by electric resistance, gas, or steam coils. Equipment capacities range from 25 to 12,000 cfm and moisture removal rates of .5 to 426 pounds of water per hour.

ICC Technologies
441 North Fifth St., Philadelphia, PA 19123 (215) 625-0700

The DESI/AIR manufactured by ICC Technologies uses a continuously rotating solid desiccant impregnated wheel. The system consists of the desiccant wheel and a heat recovery wheel, both having an axis of rotation parallel to the air flow, regeneration heat exchanger with built in gas boiler, and evaporative coolers. System capacities range from 8000 to 15,000 cfm and moisture removal rates of up to 500 pounds of water per hour.

Kathabar Systems Division, Somerset Technologies, Inc.
P.O. Box 791, New Brunswick, NJ 08903 (201) 356-6000

Kathabar systems use a liquid desiccant material. The systems consist of a conditioner (drier) and a regenerator. Ambient air passes through the conditioner where it contacts the desiccant material and the moisture is absorbed. The moisture is driven from the dilute desiccant solution in the regenerator. System configuration includes cooling coils in the conditioner so the system can maintain temperature and humidity, and regenerating heat exchanger in the regenerator that can use steam, solar energy, waste heat, or hot water for desiccant regeneration. System capacities range from 1000 to 100,000 cfm and from 80 to 10,000 pounds of water per hour.

Niagara Blower Co.
673 Ontario Street, Buffalo, NY 14207 (716) 875-2000

The Niagara Blower Company produces liquid desiccant dehumidification equipment. This system consists of a separate conditioner and regenerator. Moisture is removed from the process air stream in the regenerator and cooled to the desired temperature in the conditioner. The dilute desiccant is reconcentrated in the regenerator where heat is used to drive off moisture. Equipment capacities range in size from 1400 to 39,000 cfm.

Semco Manufacturing Inc.
P.O. Box 1797, Columbia, MO 65205 (314) 443-1481

Semco manufacturing Inc. produces a line a enthalpy recovery desiccant equipment under the name EXCLU-SIEVE. This system uses a desiccant impregnated wheel that rotates on an axis parallel to the air streams. The wheel is placed so that half is in the supply and half is in the return air streams. Heat and moisture are transferred between these streams. Desiccant regeneration is obtained by the moisture vapor pressure differences between the desiccant and the air streams. Equipment capacities range from 1000 to 61,000 cfm.

APPENDIX C: Electric and Natural Gas Prices at Selected Locations

The following electric and natural gas prices were obtained from the utility company specified and were in effect at the time of this research. These rates would be applicable for an Army installation (i.e., a special government rate schedule), or large commercial user rate schedule depending on the utility. Utility rates, particularly electric rates have increased rapidly over the past several years; it is expected that this trend will continue and the information presented here will soon be obsolete. It is therefore recommended that this information be used for comparisons only. The electric energy and gas entries include the actual energy cost along with the fuel adjustment cost, transportation cost, and all other related costs.

Atlanta, GA

Electricity - Georgia Power and Light
Natural Gas - Atlanta Gas Light Co.

	Summer	Winter
energy	$0.041/kWh	$0.041/kWh
demand	$8.00/kW	$8.00/kW
ratchet	95 percent	60 percent
months	4	8
gas	$2.54/MBtu	$2.54/MBtu

Chicago, IL

Electricity - Commonwealth Edison Co.
Natural Gas - Peoples Gas Light and Coke Co.

	Summer	Winter
energy on peak	$0.051/kWh	$0.051/kWh
off peak	$0.024/kWh	$0.024/kWh
demand	$16.41/kW	$12.83/kW
ratchet	none	none
months	N/A	N/A
gas	$2.96/MBtu	$2.96/MBtu

Houston, TX

Electricity - Houston Light and Power
Natural Gas - Entex, Inc.

	Summer	Winter
energy	$0.033/kWh	$0.033/kWh
demand	$3.40/kW	$3.40/kW
ratchet	none	none
months	6	6
gas	$3.35/MBtu	$3.35/MBtu

New York, NY

Electricity - Consolidated Edison
Natural Gas - Brooklyn Union Gas Co.

	Summer	Winter
energy	$0.035/kWh	$0.032/kWh
demand	$20.00/kW	$20.00/kW
ratchet	none	none
months	4	8
gas	$6.70/MBtu	$6.70/MBtu

San Diego, CA

Electricity - San Diego Gas and Electric Co.
Natural Gas - San Diego Gas and Electric Co.

	Summer	Winter
energy on peak	$0.080/kWh	$0.071/kWh
mid peak	$0.052/kWh	$0.045/kWh
off peak	$0.039/kWh	$0.037/kWh
demand	$17.54/kW	$4.08/kW
ratchet	none	none
months	5	7
gas	$4.13/MBtu	$4.23/MBtu
months	8	4

Washington DC

Electricity - Potomac Electric Power Co.
Natural Gas - Washington Gas Light Co.

	Summer	Winter
energy on peak	$0.061/kWh	$0.051/kWh
mid peak	$0.045/kWh	$0.045/kWh
off peak	$0.029/kWh	$0.029/kWh
demand	$15.30/kW	$15.30/kW
ratchet	none	none
months	5	7
gas	$3.10/MBtu	$3.10/MBtu

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