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Evaluating Active Desiccant Systems For Ventilating Commercial Buildings

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Over the last 15 years, active desiccant systems have become a common component of HVAC systems in commercial buildings needing lower-than-usual humidity levels. Ice arenas, supermarkets and refrigerated warehouses all contain refrigeration systems which cool air more effectively when most of the building's moisture load is removed by an active (heat-reactivated) desiccant system. Cost savings, comfort improvements and "process benefits" of extended-season operation for ice rinks, lower product temperature for supermarkets and improved safety for warehouses are usually enough to make the desiccant component a useful addition to such buildings.

More recently, active desiccant systems have been applied to ventilation systems of buildings with no obvious need for low humidity. Owners of schools, retail stores, restaurants, hotels, movie theaters and eldercare facilities do not usually demand humidity control. They usually seek only humidity moderation. That is to say, when humidity rises above 60% RH occupants may be less comfortable and mold growth may be more likely,[1] but there is seldom any loss of revenue or increase in operating cost that can be directly traced to humidity excursions. In ventilating these buildings, any benefits of active desiccant systems are less apparent, particularly since there are many other ways to remove excess moisture from the ventilation air. However, the current success of desiccants in these applications suggests that owners may care more about humidity control than is generally assumed.

ASHRAE recently made it easier for HVAC engineers to quantify peak humidity loads from outside air by including design dew points in the weather data shown in Chapter 26 of the *1997 ASHRAE Handbook—Fundamentals*. This new data is timely, because ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, affected building codes by raising recommended ventilation rates. Increasing ventilation reduced the dehumidification effectiveness of conventional packaged rooftop HVAC units and created problems with humidity control. In turn, such problems accelerated the use of outdoor air preconditioning technologies.[2] Two of the authors have developed software to evaluate the operating costs and comfort consequences of a variety of ventilation pretreatment alternatives, including active and passive desiccants.[3]

Active and Passive Systems

Desiccants remove moisture from air by sorption. Because the surface of a desiccant has a lower water vapor pressure than that of humid air, moisture migrates to the desiccant. The air leaves the desiccant device drier than when it entered. Both liquid and solid desiccant systems are used for industrial buildings and processes, but in commercial buildings, solid desiccants are more common.

The most typical method of presenting solid desiccants to an airstream is to impregnate the material into a lightweight honeycomb-shaped matrix that is then formed into a wheel. Supply air passes through one sector of the wheel and is dried. The wheel rotates slowly into a second airstream, known as the reactivation air. That air dries the desiccant, and carries the moisture out of the building.

The desiccant can be reactivated with air that is either hotter or dryer than the process air. "Active" desiccant wheels use heated air. "Passive" desiccant wheels use dry air, which is usually the building's exhaust air. An advantage of active desiccant wheels is that they dry the supply air continuously, in all weather, regardless of the moisture content of the exhaust air. Also, they can be reactivated with outside air instead of exhaust air, so they offer installation flexibility because the exhaust air does not have to be brought back to the unit. On the other

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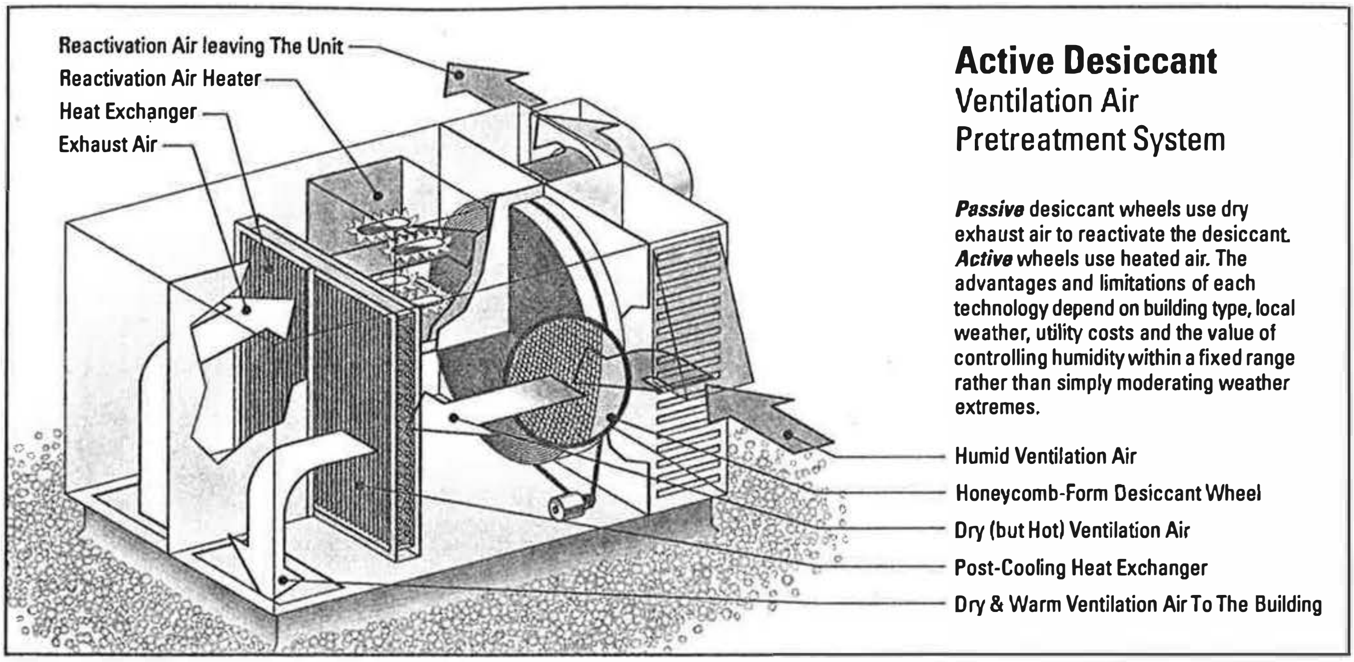


Active Desiccant
Ventilation Air
Pretreatment System

Passive **desiccant wheels use dry exhaust air to reactivate the desiccant. *Active* wheels use heated air. The advantages and limitations of each technology depend on building type, local weather, utility costs and the value of controlling humidity within a fixed range rather than simply moderating weather extremes.**

Figure 1: Active desiccant system for pretreating ventilation air.

hand, active wheels require heat input to dry the air, which adds operating cost. Passive desiccants do not remove as much moisture, and the moisture content of the supply air leaving the wheel depends on the dryness of exhaust air leaving the building. However, passive wheels reactivate the desiccant adiabatically. They require no energy apart from what is contained in the exhaust airstream. So hourly operating costs are considerably lower than for active desiccant wheels. Both technologies are used in commercial buildings to dehumidify ventilation air. Active desiccant wheels dry more deeply, achieving control of humidity. Passive desiccants usually dry more cheaply, helping the cooling system to moderate the humidity.

Active Desiccant Wheels

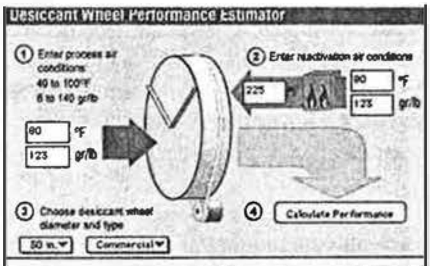
The amount of moisture removed by an active desiccant wheel depends on a number of variables including the entering air temperature and moisture, the type and quantity of desiccant, the depth of the wheel, the surface area of the honeycomb, the velocity of air moving through the wheel and the wheel rotation speed. But the most common variable used by commercial manufacturers to change the wheel's moisture removal is the temperature of the reactivation air. To make the supply air drier, the reactivation air is heated to higher temperatures. Commercial desiccant wheels are usually reactivated between 180°F and 225°F (82°C and 107°C). *Figure 2* shows the performance of a "generic" active desiccant wheel with air entering the unit at the four conditions established by ARI Standard 940-1998 for rating the performance of desiccant dehumidifiers.[4,5]

Note that the temperature rise of the dry supply air is higher when more moisture has been removed from the supply air. Between 80% and 90% of temperature rise in the supply air comes from the conversion of latent heat to sensible heat as moisture is removed from the air. The balance of the temperature rise comes from the heat carried over by the wheel as it rotates from the hot reactivation air to the cooler supply air.

In some applications, sensible heat is useful. In supermarkets, for example, the display cases over-chill the aisles unless hot air is supplied to the frozen food areas. But in most ventilation-related applications, the hot supply air must be at least partly cooled before it is delivered to the occupied space, which affects the operating cost of active desiccant wheels.

Post-Cooling Dry Supply Air

Figure 3 shows the heat exchanger and evaporative cooler that are often used to cool the supply air at low cost.[6] The amount of heat removed by the postcooler depends on how cool the air is on the other side of the exchanger. Ideally, the system would take exhaust air from the building and evaporatively cool it. That configuration provides maximum postcooling at minimum cost.



① Enter process air conditions 40 to 100°F 6 to 140 gr/lb
80 °F
123 gr/lb

② Enter reactivation air conditions
225
80 °F
123 gr/lb

③ Choose desiccant wheel diameter and type
50 in.
Commercial

④ Calculate Performance

Supply Air Velocity: 600 fpm [3.0 m/s]
Reactivation Air: 225°F [107.2°C]

ARI Rating Point	Entering		Leaving		
	°F	gr/lb	°F	gr/lb	Dpt °F
1.	95	98	127	57	52
2.	80	123	126	61	54
3.	80	77	114	33	38
4.	45	44	75	7	5
	°C	g/kg	°C	g/kg	Dpt °C
1.	35.0	14.0	52.7	8.1	11.1
2.	26.7	17.5	52.2	8.7	12.2
3.	26.7	11.0	45.5	4.7	3.3
4.	7.2	6.3	24.0	1.0	-15.0

Figure 2: Typical performance of active desiccant wheels at ARI rating points.[4,5]

However, in many cases exhaust air is not available where ventilation air enters the building. And in some cases, owners prefer to avoid the maintenance associated with an evaporative cooler. In those situations, the post cooler simply uses untreated outside air for the heat exchanger, and less cooling is accomplished in the desiccant system, leaving a residual sensible load to be removed by the building's cooling systems.

Drying Ventilation Air to Improve Comfort

In commercial HVAC systems, active desiccant systems generally dry the ventilation air because it represents the largest moisture load (*Figure 4*). When the ventilation air can be dried deeply (below the desired condition in the building) the incoming air acts as a "sponge," collecting excess moisture from the space and keeping the humidity at a defined level. Also, removing the moisture load allows cooling systems to perform more effectively. Without the need to remove a large moisture load, the cooling units do not have to overcool the air. The comfort advantage is most perceptible at "part-load conditions" when the sensible load is low, but the moisture load remains high.

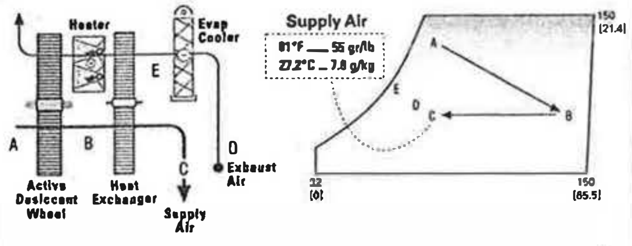
Figure 5 shows that in a typical year in West Palm Beach, Fla. there are 3,538 hours per year of moisture load in ventilation air, without a simultaneous sensible heat load. In low-cost commercial HVAC systems, these are usually hours when a cooling system alone creates overly cool and humid conditions inside the building. Adding a dedicated dehumidification device—either cooling or desiccant-based—adds initial cost, but improves comfort. The dehumidifier responds to a humidistat, and the cooling units respond to the thermostat. Separating the controls and the equipment achieves more uniform conditions for both temperature and humidity. Control, rather than just moderation is achieved—but at what cost? Adding ventilation pretreatment equipment certainly increases costs in that part of the system. However, proponents of dedicated dehumidification systems contend that by removing moisture load from ventilation air, excess cooling capacity can be subtracted from the rest of the system, saving enough to offset the cost of the pretreatment equipment. This assertion has been supported by field research results in some cases,[7] but for most commercial buildings, humidity control cost questions are not so easily answered. The answers depend on the owner's expectations.

In commercial construction, the client seldom expects precise control in a narrow range for all 8,760 hours per year. To assess the value of humidity control vs. moderation, the owner needs to know how many hours per year one might expect comfort with different technical alternatives. Computer programs have been developed to explore this question, modeling energy costs vs. comfort for many equipment alternatives in selected commercial buildings.[3]

Modeling Humidity Control: Costs vs. Comfort

Evaluating the costs vs. comfort cannot be done adequately by examining equipment behavior only at peak design conditions. One might logically assume that if the system produces comfortable humidity levels under peak load conditions, it will also produce comfort at part-load conditions. But such is not the case with thermostatically-controlled cooling systems. With commercially packaged rooftop cooling units, dehumidification only occurs when the unit runs to remove heat. When the sensible load is low, the short run-time reduces dehumidification effectiveness.

Ventilation Air with Active Desiccant Dehumidification



	A	B	C	D	E
Temperature (°F)	83	144	81	75	65
Moisture (gr/lb)	123	55	55	65	82
Temperature (°C)	28.3	62.2	27.2	24.0	18.3
Moisture (g/kg)	17.5	7.8	7.8	9.3	11.7

Figure 3: Post cooling dry ventilation air using an indirect evaporative cooler.[6]

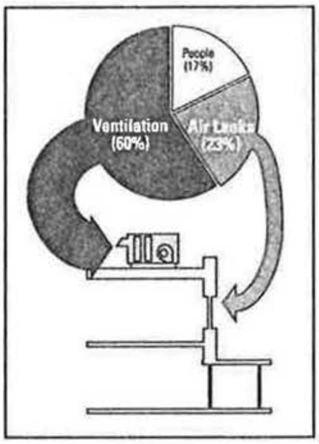


Figure 4: Principal sources of moisture load in commercial buildings.

Figure 6 shows this phenomenon clearly. Even systems which use passive desiccant wheels have difficulty moderating humidity if the sensible load in the space is low.[8] Moisture loads from ventilation air raise the humidity in the space. This problem is even more common when HVAC designers succumb to the temptation to oversize the cooling units. With oversized equipment, run-times are even shorter, so dehumidification capacity may be essentially zero. Short running cycles may not allow condensed moisture on evaporator surfaces to reach the drain pan. If air flows continuously through the coil, moisture will re-evaporate into the air, resulting in no actual moisture removal from the building. On the other hand, these potential problems do not occur all year round. So an hourly building model is the most practical means of comparing the magnitude of the problem with the cost of its solution.

The program developed for this purpose relies on the DOE 2.1E calculation engine developed by the Lawrence Berkeley Laboratory for the U.S. Department of Energy.[9] That generalized program has been modified in two ways. A graphical interface was added, and the program is "pre-loaded" with typical construction, operational parameters, hourly weather data, utility rate schedules and equipment alternatives for 12 specific commercial buildings that require either low humidity or high ventilation rates. These include:

- Schools.
- Quick-service restaurants.
- Skilled-nursing eldercare buildings.

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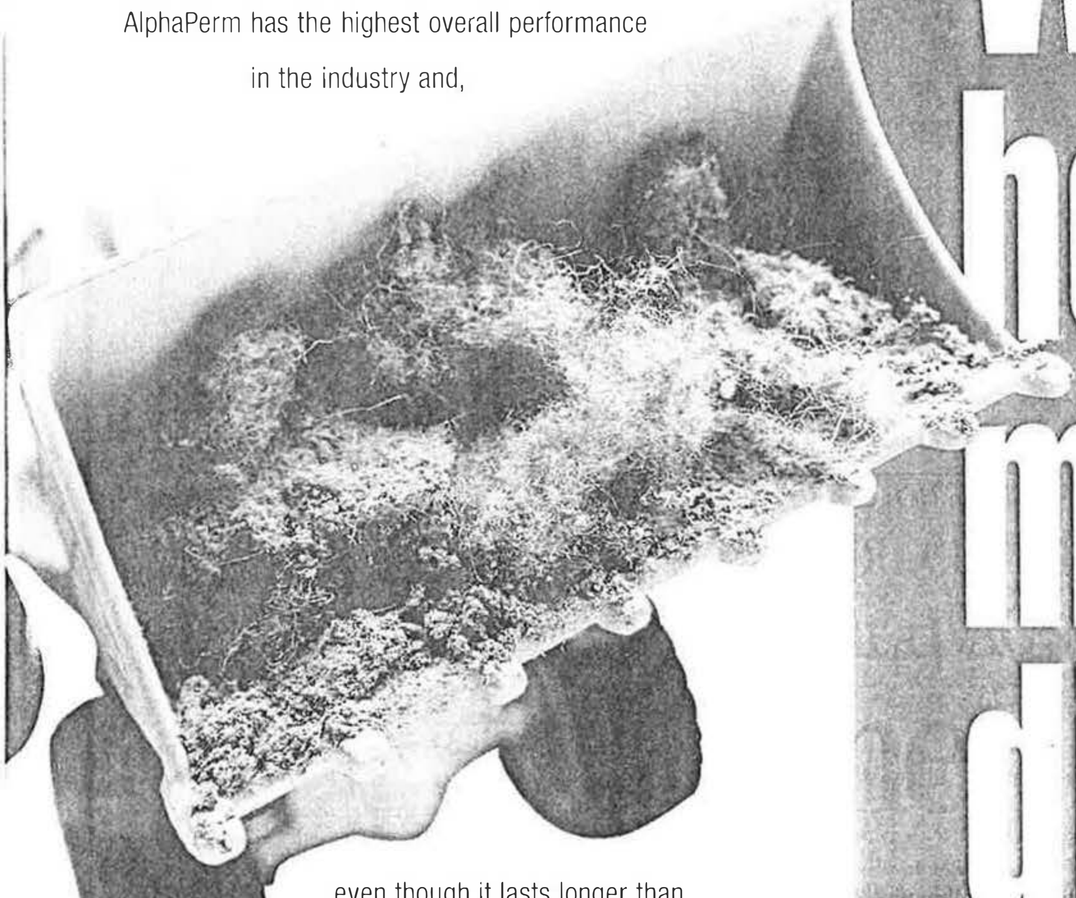

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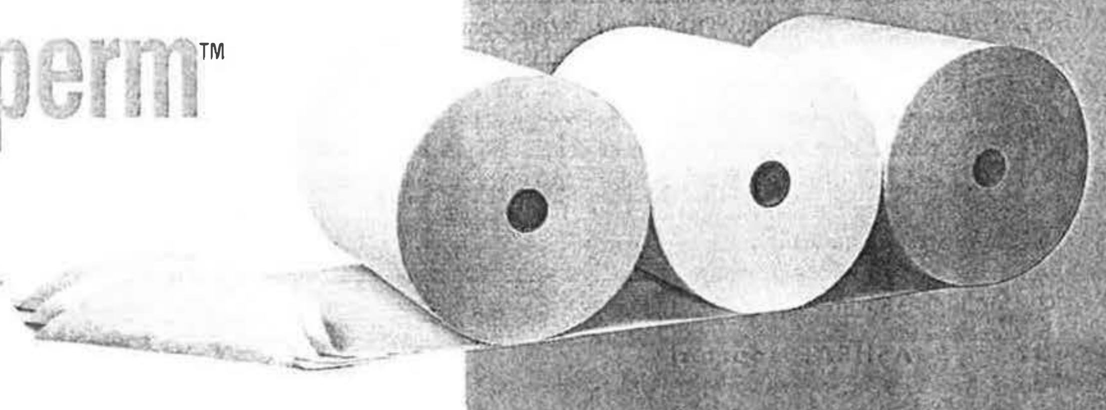

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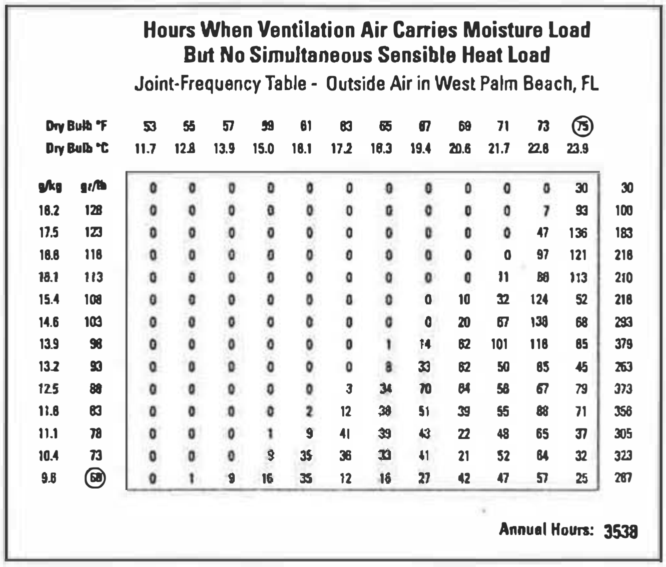


Hours When Ventilation Air Carries Moisture Load But No Simultaneous Sensible Heat Load

Joint-Frequency Table - Outside Air in West Palm Beach, FL

	Dry Bulb °F	53	55	57	59	61	63	65	67	69	71	73	⑦⑤ 75	
	Dry Bulb °C	11.7	12.8	13.9	15.0	16.1	17.2	18.3	19.4	20.6	21.7	22.8	23.9	
g/kg	gr/lb	0	0	0	0	0	0	0	0	0	0	0	30	30
18.2	128	0	0	0	0	0	0	0	0	0	0	7	93	100
17.5	123	0	0	0	0	0	0	0	0	0	0	47	136	183
16.8	118	0	0	0	0	0	0	0	0	0	0	97	121	218
16.1	113	0	0	0	0	0	0	0	0	0	11	86	113	210
15.4	108	0	0	0	0	0	0	0	0	10	32	124	52	218
14.6	103	0	0	0	0	0	0	0	0	20	67	138	68	293
13.9	98	0	0	0	0	0	0	1	14	62	101	118	85	379
13.2	93	0	0	0	0	0	0	8	33	62	50	85	45	263
12.5	88	0	0	0	0	0	3	34	70	64	58	67	79	373
11.8	83	0	0	0	0	2	12	38	51	39	55	88	71	356
11.1	78	0	0	0	1	9	41	39	43	22	48	65	37	305
10.4	73	0	0	0	9	35	36	33	41	21	52	64	32	323
9.8	⑥⑧ 68	0	1	9	16	35	12	16	27	42	47	57	25	287

Annual Hours: 3538

Figure 5: Number of hours when ventilation air is cool but excessively humid.

- Low-rise hotels.
- High-rise hotels.
- Low-rise offices.
- Hospital operating rooms.
- Movie theaters.
- Ice rinks.
- Refrigerated warehouses.
- Supermarkets.
- Retail stores.

Input time is kept to a minimum by pre-loading typical construction details for these structures. The user can make any changes needed to the defaults, and run a full-year, 8,760-hour approximation of the building's hourly energy use and comfort levels in less than three minutes. This is in sharp contrast to the many hours needed to enter necessary building details into generalized building simulations.

The purpose of this particular program is to allow rapid, but still-credible comparisons of equipment alternatives that reflect actual utility rate structures, rather than to achieve an exact match to measured operational costs. The program trades away some degree of flexibility in defining application and HVAC system configuration to gain speed and convenience.

Comfort & Energy Costs in Movie Theaters

Movie theaters differ from other commercial buildings in several significant ways. They have virtually no glazing, apart from the lobby. They have heavy insulation for sound isolation, and their highest occupancy occurs during evening hours. Also, they have very high occupant density compared to other commercial buildings. More people require more ventilation per unit of floor space. All of these factors combine to keep sensible heat loads to a minimum while moisture loads from people and ventilation remain quite high.

Finally, the theater competes commercially with renting videos for home viewing. The video offers privacy, convenience and low cost. The theater offers enhanced visuals, better sound and the latest movies. But such competition means that the perceived freshness and comfort of the theater air has a value, and ideally should not be less desirable than the environment available when viewing a video at home.

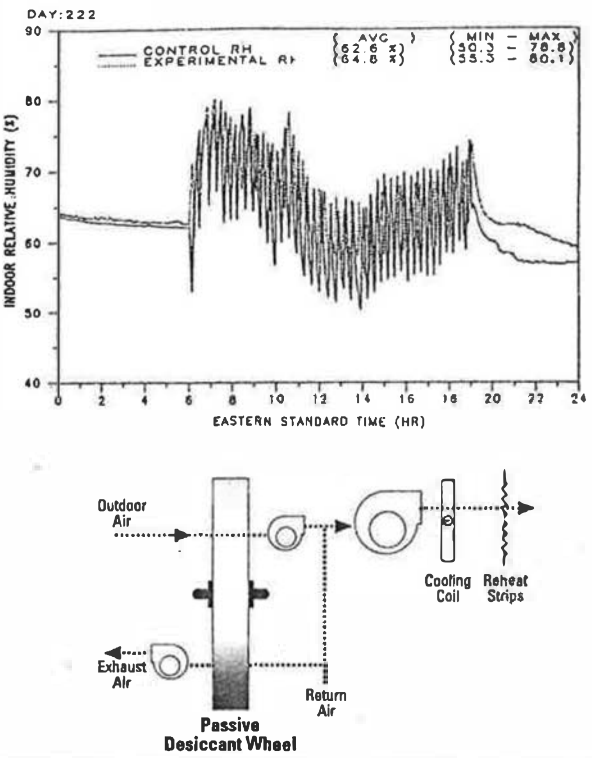
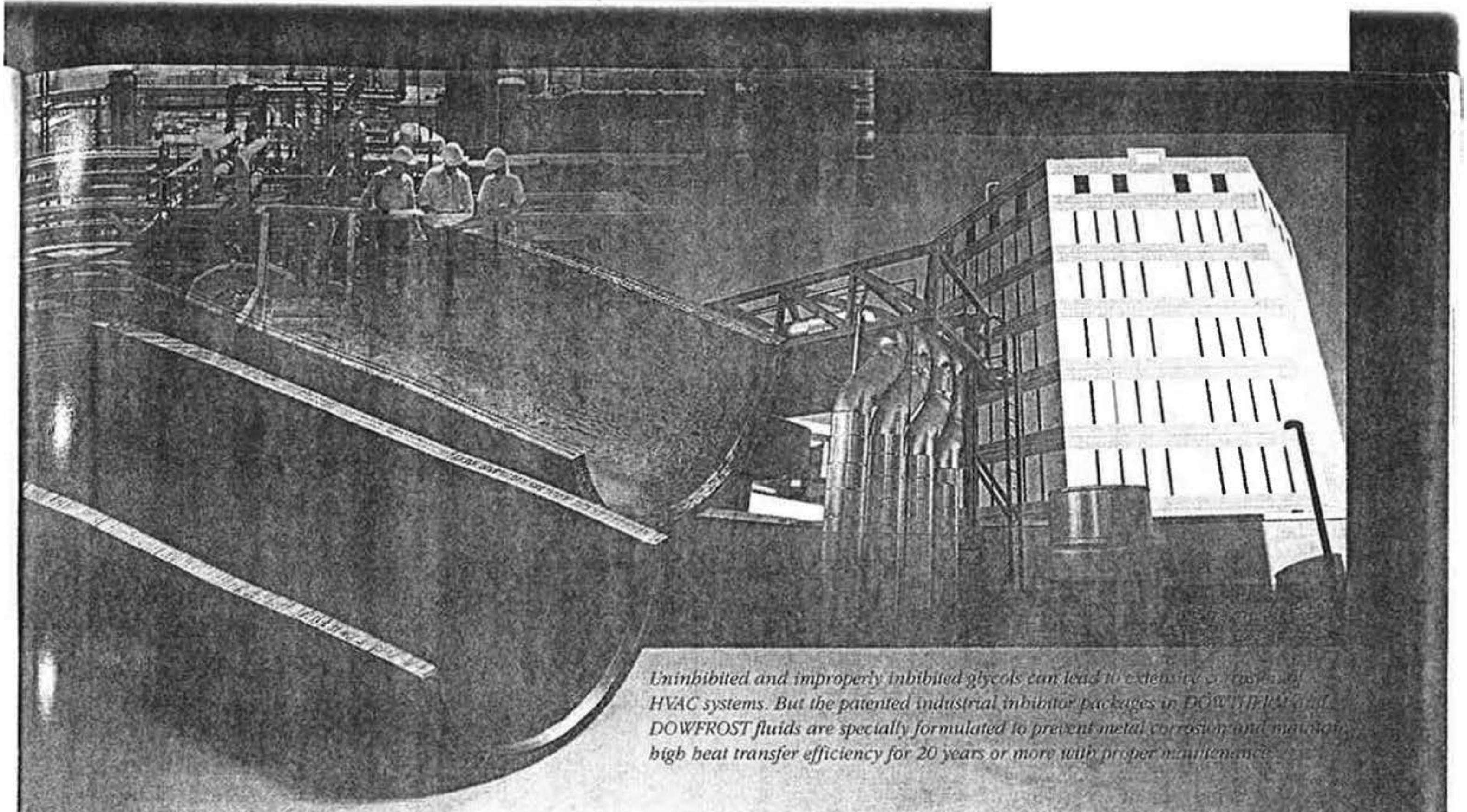


Figure 6: If sensible heat loads are low, the compressor does not run long enough to keep humidity low. Passive desiccant wheels only dehumidify when the exhaust air is dry.[8]

The annual energy simulation program was used to compare two equipment alternatives for pretreating ventilation air for a movie theater. The same building parameters were used, changing the utility rates and the weather to reflect local conditions at 17 different U.S. locations. HVAC equipment included packaged gas-electric rooftop cooling/heating units for temperature control. The equipment was resized for each location based on either the ASHRAE 0.4% dry bulb or 0.4% dew point, depending on which condition represented the highest enthalpy.

The buildings were also equipped with dedicated ventilation pretreatment units. These contained either passive or active desiccant wheels to remove excess moisture from incoming air. About 50% of the building's exhaust air is available for pretreatment through passive desiccants, or for postcooling of active desiccants. The balance of the exhaust is used to cool the projectors. That air leaves the building in many small increments of hot, humid air. It is not cost-effective to collect it for use in either system.

The simulation results are contained in *Table 1*. The locations have been sorted in order of increasing comfort with the lower-cost equipment (passive desiccant wheels). For purposes of this comparison, discomfort is defined rather informally as the "num-



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	Corrosion Rate (mils per year)				
	Water	**Uninhibited Propylene Glycol**	**DOWFROST HD Fluid**	**Uninhibited Ethylene Glycol**	**DOWTHERM SR-1 Fluid**
Copper	0.08	0.16	0.04	0.16	0.12
Solder	3.14	34.7	0.06	56.5	0.13
Brass	0.23	0.20	0.08	0.46	0.12
Mild Steel	9.69	9.80	0.04	44.5	0.04
Cast Iron	21.2	16.2	0.05	55.7	0.13
Aluminum	13.2	1.80	+0.36	19.8	0.44

Rates in excess of 0.5 mpy (2.5 for aluminum) are generally evidence of inadequate corrosion protection.

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ber of occupied hours when the relative humidity in the theaters exceeds 60%."

For example, the model estimates that in a theater equipped with passive desiccant wheels in Miami, the occupants will experience about 2,336 hours when the relative humidity is more than 60%. In contrast, the same building located in Minneapolis will be more comfortable, with only 613 occupied hours when humidity is more than 60% RH. The "discomfort" column for the active desiccant alternative is vacant, with humidity held below 60% RH for all hours during the year. This result is expected, since the active desiccant wheel dries air more deeply, and dries that air according to the moisture load in the space rather than only when the cooling units operate, as in the case of the passive desiccant wheels.

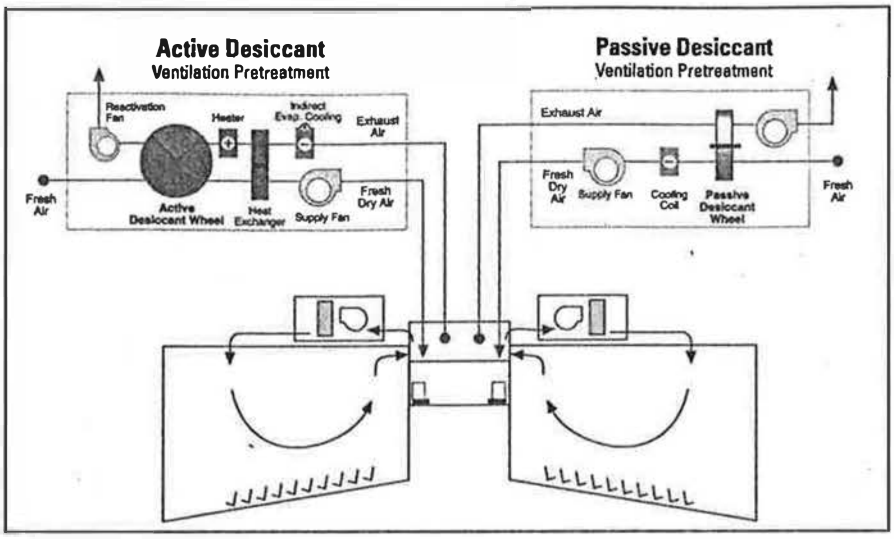

Figure 7: The program compared two options for dedicated ventilation air pretreatment: active vs. passive desiccant wheels. Internal loads were removed by conventional packaged gas/electric rooftop units.

The less-expected result is the operating cost advantage enjoyed by the active desiccant system. In all these locations, better comfort costs less than poorer comfort. At the extremes: in Tampa, Fla., the active desiccant theater operates for $1,429 less per year than the passive desiccant theater. In New York City, the active desiccant cost advantage increases to $20,572 per year. These results may be partly explained by the small amount of exhaust air available for the passive desiccant alternative. In other types of buildings, using 100% of the exhaust in the passive desiccant wheel considerably improves economics of that alternative.

Another contributor to cost differences is the cost of energy used for dehumidification. Electric power is used to remove moisture with passive desiccant wheels, since dehumidification depends primarily on the action of the cooling coils. In New York City, the net usage-based power costs for this building are $0.20 per kWh. Converting the local cost of gas to the same units, the active desiccant unit uses energy at a cost of $0.03 per kWh. Since natural gas costs are essentially 15% of the cost of power, the cost advantage of active desiccants in this particular application is easier to understand.

An interesting pattern emerges when comparing the comfort differences to cost differences. The comfort differences are strongly influenced by climate, but in most cases, the cost differences relate primarily to the cost of electrical power. For example, with the passive desiccant system, the least comfortable locations are Miami, Tampa, Houston and Dallas. That is not surprising, since all are humid

Annual Operating Costs & Comfort (Movie Theaters)

	Usage-Based Net Utility Rates		Rooftops with Passive Desiccant				Rooftops with Active Desiccant				Cost Advantage Active (Passive) ($ 000)
	Power $/kWh	Gas $/kWh	Power ($ 000)	Gas ($ 000)	Total ($ 000)	Discomfort (Hrs>60%)	Power ($ 000)	Gas ($ 000)	Total ($ 000)	Discomfort (Hrs>60%)	
New York, NY	0.20	0.03	66.9	27.8	94.7	713	49.9	24.2	74.1	0	21
Charleston, SC	0.08	0.03	41.5	19.0	60.5	1,212	32.0	13.4	45.4	0	15
Cleveland, OH	0.14	0.02	47.2	16.2	63.4	675	34.4	14.3	48.7	0	15
Baltimore, MD	0.13	0.02	48.2	17.1	65.3	978	38.4	15.3	53.7	0	12
Chicago, IL	0.13	0.01	42.4	12.3	54.7	618	32.1	11.2	43.3	0	11
New Orleans, LA	0.09	0.02	57.3	15.7	72.9	1,173	46.7	16.9	63.6	0	9
Atlanta, GA	0.10	0.02	42.8	11.3	54.1	1,255	36.6	8.7	45.4	0	9
Nashville, TN	0.08	0.02	36.1	13.4	49.5	1,170	28.4	13.9	42.3	0	7
Raleigh, NC	0.08	0.02	32.4	12.5	44.9	1,121	27.4	11.3	38.7	0	6
Raleigh, NC	0.08	0.02	32.4	12.5	44.9	1,121	27.4	11.3	38.7	0	6
Dallas, TX	0.09	0.02	44.8	9.2	54.0	1,540	36.6	11.6	48.1	0	6
St. Louis, MO	0.09	0.02	38.4	16.7	55.1	973	33.3	16.0	49.3	0	6
Minneapolis, MN	0.08	0.02	25.8	21.8	47.6	613	21.1	21.1	42.2	0	5
Houston, TX	0.08	0.02	49.4	11.5	61.0	1,671	41.8	14.5	56.3	0	5
Jackson, MS	0.05	0.01	28.1	9.7	37.8	1,515	23.7	10.5	34.2	0	4
Miami, FL	0.08	0.02	58.9	13.8	72.6	2,336	53.4	17.8	71.2	0	1
Tampa, FL	0.07	0.02	48.8	15.2	63.9	1,861	40.9	21.6	62.5	0	1

Table 1: Comparing energy costs and comfort in movie theaters using an 8,760-hour building simulation program.[3] *(Rates shown in Tables 1 and 2 are "net per year:" Total costs ÷ total usage.)*

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In a critical application that means 2 minutes of down time versus 2 hours!

And what about the cost of those "high-priced" cylinders? The cylinder shown at left is just $62! That's a $32 savings over the labor cost to clean the pan-coil!

By the way, the cost of most pan-coil electric elements range from $200 to $400, and they DO burn out!

Where do you clean them? Clean the pan-coil unit wherever its installed because you can't take it to the sink. And we wouldn't recommend wearing a suit!

The SD 2000 represents the state of the art in electric humidifiers, featuring rapid startup and shut down, anti-foaming circuitry, conductivity control, and the most complete diagnostics of any unit in the world. Energy efficiency stays at a whopping 94% over 98% of the cylinder life. No pan-coil unit can match that!

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climates. But in terms of cost, the cities with the largest advantage for active desiccants are New York, Charleston, Cleveland and Baltimore, which have very dissimilar climates, but consistently high power costs. Charleston is the exception—with relatively low power costs—balanced by a hot and humid climate.

Comfort and Energy Costs

Operational costs for different building types vary widely, which strongly affects the advantages and limitations of equipment alternatives. The data in *Table 2* shows comfort and costs for passive and active desiccant-equipped buildings, all of which are located in New York City. There are striking differences between this same-location comparison and the comparison of theaters in different locations.

Where theaters always displayed both cost and comfort advantages for active desiccants, the results change considerably between different structure types in New York City. Comfort advantages still accrue to all active desiccant buildings, but the cost advantage shifts to passive desiccants. While the movie theater and school still display cost advantages for active desiccants, passive desiccants save operating costs in all other structure types.

So decision-making becomes more complex. The owner and HVAC designer must decide what value to place on improved comfort. A developer will probably conclude that gaining five hours of comfort in a low-rise office building is not worth spending an additional $1,444 per year for active desiccants. On the other hand, the owner of a skilled nursing facility may be more inclined to spend an extra $2,462 each year to gain an additional 1,611 hours of comfort.

Conclusions

Utility rates drive the operating cost advantages and limitations of each technology-a fact that is difficult to appreciate and quantify without an annual hourly simulation such as this program provides. Consider the cost of operating HVAC systems with active desiccant ventilation pretreatment in similar climates. In New Orleans it costs $63,600 each year to operate the HVAC for the movie theater, while just 180 miles away in Jackson, Miss., it costs only $34,200.

Finally, operating costs are not the only concern. Comfort has a value that varies according to its duration and according to the preferences of different building owners. Clearly, it is useful to examine the local conditions of both climate and utility costs before making a blanket judgement about the cost-effectiveness of any given technology. The authors speculate that hourly simulation will be even more important in the future, as demand and usage costs for power change radically under deregulation, and as humidity-related comfort expectations change for occupants of commercial buildings.

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	Size (000) ft2 [m2]	Usage-Based Net Utility Rates Power $/kWh	Gas $/kWh	Rooftops with Passive Desiccant Power ($ 000)	Gas ($ 000)	Total ($ 000)	Discomfort (Hrs>60%)	Rooftops with Active Desiccant Power ($ 000)	Gas ($ 000)	Total ($ 000)	Discomfort (Hrs>60%)	Cost Advantage Active (Passive) ($ 000)
Low-Rise Hotel	40 [3.7]	0.13	0.03	80.9	23.2	104.1	1,718	84.4	23.7	108.0	0	(4)
Skilled Nursing	45 [4.2]	0.14	0.03	84.0	30.0	114.0	1,611	84.7	31.8	116.4	0	(2)
Hospital, plus ORs	22 [2.0]	0.11	0.03	1,195.4	309.3	1,504.6	1,193	1,180.2	348.0	1,528.2	0	(24)
Movie Theater	40 [3.7]	0.20	0.03	66.9	27.8	94.7	713	49.9	24.2	74.1	0	21
School	165 [15.3]	0.18	0.03	395.3	97.9	493.2	353	294.6	131.4	426.0	0	67
Retail Store	6 [0.5]	0.12	0.03	132.2	16.1	148.3	330	135.8	20.3	156.2	0	(8)
Low-Rise Office	30 [2.8]	0.17	0.04	68.8	4.0	72.8	5	69.6	4.6	74.3	0	(1)

Table 2: Comparing energy costs and comfort for different structures in the same climate and utility rate structure.[3]

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