DOAS & Desiccants

This pairing can represent a great strategy — if you choose your tactics wisely. When is passive or active the better desiccant approach? When is one out of the question? We'll discuss how to control the latent load, arrive at a smart design decision for the circumstance, and consider recent research on first cost and performance.

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Two essential attributes of mechanical systems intended to provide building occupants with good IAQ and indoor environmental quality (IEQ) are uncompromised ventilation air delivery and ensured humidity control.

Engineers have numerous mechanical system selection options at their fingertips, however, most options fail one or both of the required attributes. One mechanical system capable of economically meeting the essential attributes is a properly designed dedicated outdoor air system[1]. DOASs are designed to deliver at least the minimum 100% OA specified by ASHRAE 62.1 to each occupant, and to completely and continually meet the individual space latent cooling loads with dry air.

SELECTING THE DOAS SUPPLY AIR DEWPOINT TEMPERATURE

A DOAS, delivering the required ASHRAE 62.1 ventilation air, rarely supplies more than a small fraction of the air delivered by an all air system, such as a VAV. Consequently, the DOAS is seldom able to meet the space sensible loads, even if the supply air (SA) dewpoint temperature (DPT) is low (40°F to 50°), thus requiring parallel sensible cooling equipment. The design engineer must make a conscious decision to allow the parallel cooling equipment to also meet either none or a part of the space latent load.

Some parallel cooling equipment can accommodate latent cooling (e.g., fancoil units). Other parallel cooling equipment — such as chilled ceilings, beams, and floors — must not be allowed to handle any of the space latent load, in order to avoid condensation on the cool surfaces.

Even when the terminal equipment is permitted to remove moisture, the drain pans become septic amplifiers throughout the facility and may adversely affect the IEQ and IAQ. Consequently, one should generally assign the DOAS the entire task of moisture removal, both in the OA and within the occupied spaces.

When the DOAS has the task of removing all moisture generated and/or leaked into the occupied spaces, the required SA DPT is a function of the design space DPT (related to the design space drybulb temperature (DBT) and % rh), the latent load, and the rate of DOAS SA to an individual space. Each individual space needs to be scrutinized.

The required SA DPT for DOAS is often around 45°, or below the ordinary 52° DPT associated with conventional VAV. Increasing the SA flow rates to the space requiring the lowest SA DPT (generally at the perimeter) will allow the design DPT to be increased, relaxing the SA DPT required for the entire facility.

The lower than normal SA DPTs have led some to employ low temperature techniques, others to use ice thermal storage and associated low chilled water/brine temperatures, and still others to employ desiccants (active desiccant and passive dehumidification components) with conventional temperature DX cooling equipment.

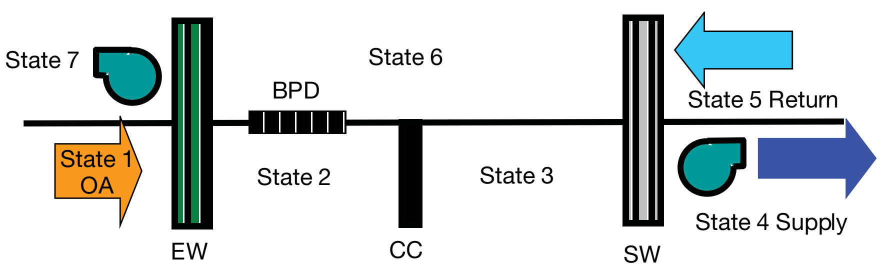
Desiccants use either adsorption or absorption to attract water molecules to accumulate at the desiccant. Adsorption desiccants include zeolites (molecular sieve) and silica gel. Absorption des-

More to the story

Humidity control and DOAS are big topics. So big, in fact, that we have more to offer on the subject. For an expanded version of this article, plus additional graphics to support the text, visit its online version at *www.esmagazine.com*.

Symbol Key for Figures 1, 5, 7, 9, and 11

SW	EW	CC	PDHC	HC	BPD	ADesW
Sensible wheel	Enthalpy wheel	Cooling coil	Passive dehumidification component	Heating coil	Bypass damper	Active desiccant wheel



Enthalpy Wheel (EW)+Cooling (CC)+Sensible Wheel (SW)

State #	1,OA	2	3	4, Supply	5, Return	6	7
DBT, ˚F	84	64	45	68	75	52.5	81
W, gr/lbm	148	87	43	43	58.2	58	134

EW+CC

State #	1,OA	2	3	4, Supply	5, Return	6	7
DBT, ˚F	84	79	45	45	75	75	85
W, gr/lbm	148	87	43	43	58.2	58.2	138

CC

State #	1,OA	2	3	4, Supply	5, Return	6	7
DBT, ˚F	84	84	45	45	75	75	75
W, gr/lbm	148	148	43	43	58.2	58.2	58.2

FIGURE 1. Enthalpy wheel (EW), cooling coil (CC), and sensible wheel (SW) arrangements.

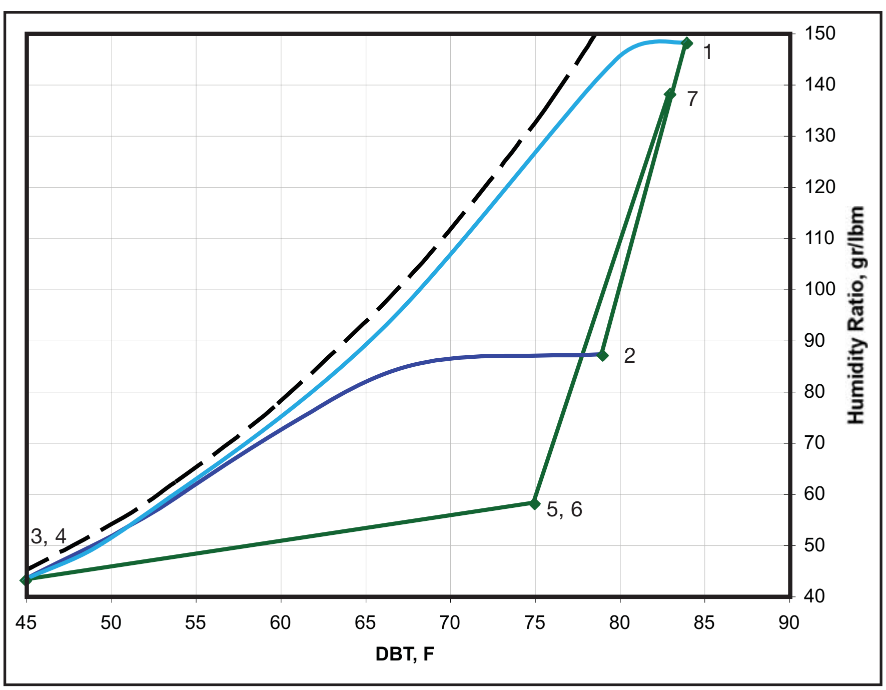


FIGURE 2. Psychrometric chart for CC and EW+CC.

Active desiccant behavior approximates a constant enthalpy process. The active desiccant wheel's low rotational speed limits the sensible heat transferred between the process and regeneration airstreams. The TER device performs psychrometrically like the adiabatic mixing of two airstreams (that is the leaving conditioned air state point is on a straight line between the two entering air state points).

iccants include hygroscopic salts such as lithium chloride.

DOAS EQUIPMENT IN THE MARKETPLACE

Due to limited space, this article can not discuss all equipment. However, let's attempt to cover the general classes.

NO ENERGY RECOVERY CLASS

The simplest and lowest first-cost class is simply a cooling coil (CC) used to suppress the SA DPT to 52° (removing all the OA latent load, but only part of the space latent load), and allowing the parallel equipment to take care of the balance of the sensible and latent loads not accommodated by the ventilation air. The 52° SA DOAS mimics a VAV system when the VAV box has modulated to the minimum air mode. Neutral air temperatures would never seem to be desired. Modulating the ventilation airflow rates based upon occupancy could save cooling or heating energy at off-design occupancy ventilation rates, since there is no heat recovery in this class.

Rarely, if ever, would the 52° SA DPT accommodate all of the space latent loads, so it could not be used with chilled ceilings, beams, or floors.

Great care needs to be exercised when selecting such a DOAS, since the unit handles 100% OA and will experience very high latent to total loads (small sensible heat ratio [SHR]). That is something most off-the-shelf DX units are not capable of. Since the SHR for most packaged DX equipment is about 0.7, the high latent loads of the OA require equipment capable of delivering sensible cooling well beyond the needs. To prevent overcooling, the equipment cycles on and off without providing adequate dehumidification, unless equipped with reheat.

TOTAL ENERGY RECOVERY CLASS

The next step in the progression of DOAS equipment classes adds a total energy recovery (TER) component (wheel or plate type) upstream of the CC to recover total energy from the exhaust airstream. TER (employing passive desiccants) is not able to drop the SA DPT low enough to do space dehumidification by itself, so a CC is still required. ASHRAE 90.1 requires TER (for most climates) in all but low-rise buildings when the DOAS is handling 5,000 cfm or more. The TER device employs a desiccant that is regenerated without the expenditure

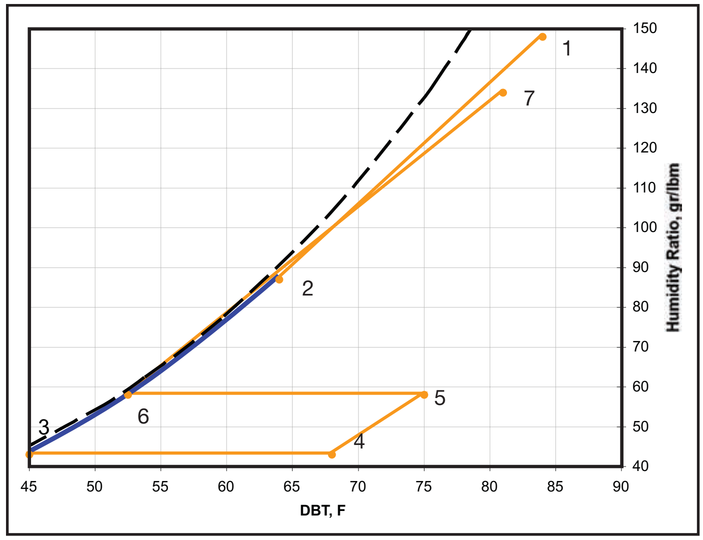


FIGURE 3. Psychrometric chart for EW+CC+SW.

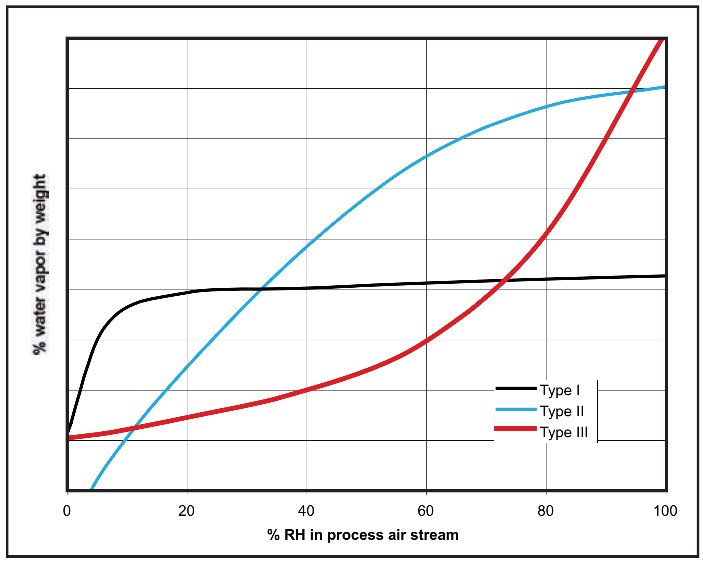
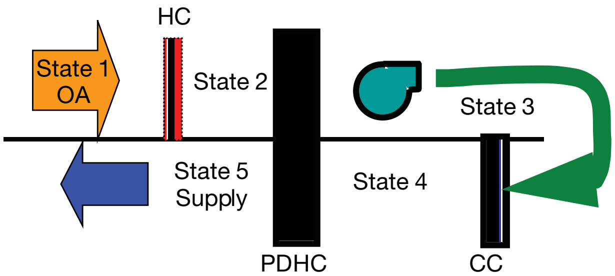


FIGURE 4. Representative sorption isotherms for three desiccant types at 75°F.

of auxiliary heat. Wheel-type TER components, also referred to as enthalpy wheels, typically rotate at about 20 rpm or higher.

A TER component does not perform psychrometrically like an active solid desiccant wheel (which requires regeneration temperatures of 150° to 300° and operates at about 1/6 to 1/2 rpm). Active desiccant behavior approximates a constant enthalpy process. The active desiccant wheel's low rotational speed limits the sensible heat transferred between the process and regeneration airstreams. The TER device performs psychrometrically like the adiabatic mixing of two airstreams (that is the leaving conditioned air state point is on a straight line between the two entering air state points).

TER equipment often exhibits effectivenesses between 0.6 and 0.8. That means the TER device will condition OA, for example, along a straight line between the OA and relief air conditions, to within 20% to 40% of the relief air state point. The result is a huge reduction in the CC load, a great reduction in the variability seen by the CC,



State #	1,OA	2	3	4	5, Supply
DBT, ˚F	84	89.5	84.4	48	53.1
W, gr/lbm	148	148	153.4	48.6	43

FIGURE 5. Passive dehumidification component (PDHC) and CC without energy recovery.

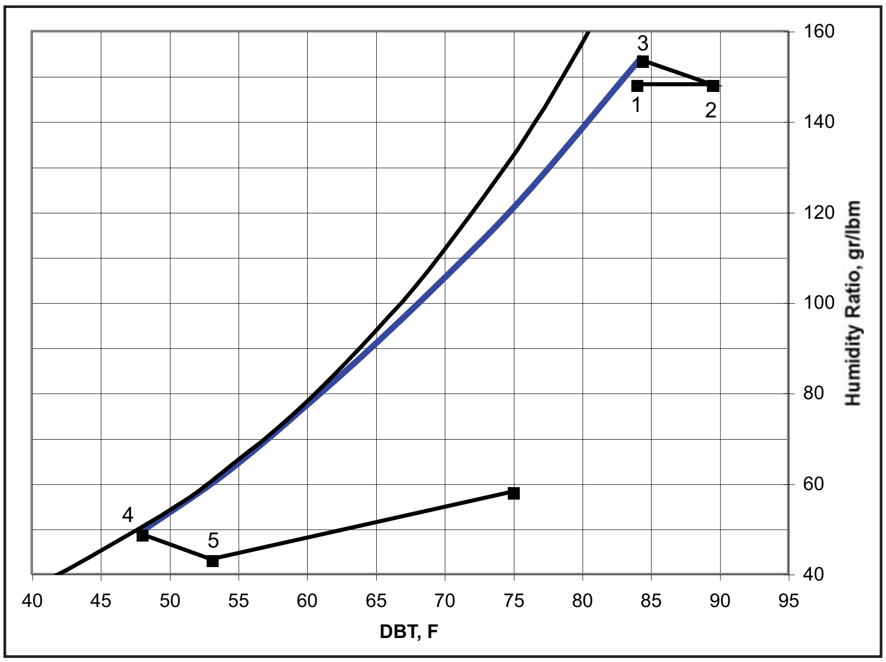
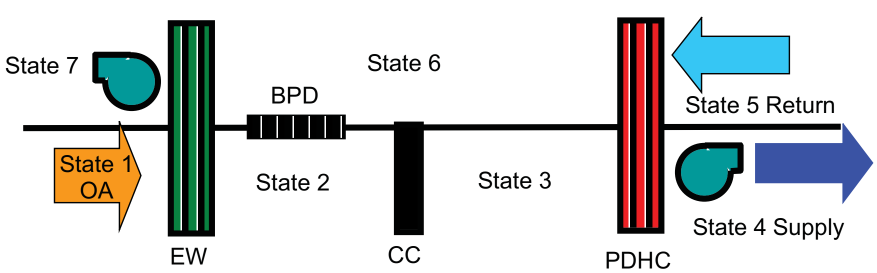


FIGURE 6. PDHC+CC psychrometric chart.



State #	1,OA	2	3	4, Supply	5, Return	6	7
DPT, ˚F	84	69.4	53.4	63.3	75	65.1	82.9
W, gr/lbm	148	95.4	60.3	43	58.2	79.9	144

FIGURE 7. One arrangement of PDHC and CC with EW (EW+CC+PDHC).

and most importantly, a great reduction in the latent component of the coil load. This makes it possible for ordinary off-the-shelf DX cooling equipment to handle the 100% OA loads without oversizing. Design SHR for coils handling 100% OA are about 0.3 to 0.4, while the SHR capability of most packaged equipment is about 0.65 to 0.8[2].

To illustrate the SHR issue, assume a 20-ton CC (working alone) cooling and dehumidifying 100% OA. Also assume that the CC is required to meet a SHR of 0.35 (35% of the total load is sensible cooling and 65% is latent cooling). That means the sensible load is 7 tons and the latent load is 13 tons.

If a conventional 20-ton DX unit were selected for the application capable of handling a load with a SHR of 0.7, it could do 14 tons of sensible cooling and 6 tons of latent cooling — less than half the required latent cooling.

In order to meet the OA latent load, a 43-ton unit with the same 0.7 SHR capability would be required. The larger unit is capable of 30 tons of sensible cooling when only 7 is needed. To prevent cycling and loss of dehumidification, reheating the SA will be required to reduce the sensible overcooling. On the contrary, an EW at the same OA conditions would reduce the CC load to 16 tons, and elevate the SHR to about 0.7 (about 11 tons sensible and 5 tons latent), thus illustrating the significant benefits of EWs integrated with a CC in DOAS applications.

Low DPTs are not friends of DX equipment, and chilled water (brine) systems require lower than normal fluid temperatures. So unless ice storage is used as the cooling source, the TER-CC class is generally limited to SA DPTs around 50° to 55°.

When applying TER, care should be exercised to ensure that building pressurization is not lost in an effort to maximize energy recovery.

Finally, use of wheel type TER devices is not recommended if the exhaust airstream contains dangerous material (toilet exhaust is acceptable). When this class is used to mechanically produce low DPTs, (in the low 40°s) and a higher SA DBT is needed at design or off-design, then consider either hot gas reheat or sensible heat recovery from the exhaust airstream for energy efficiency.

A schematic of a system in this class consisting of an EW, CC, and SW is illustrated in Figure 1, along with the tabular thermodynamic state points throughout the system for the CC alone, EW+CC, and EW+CC+SW. The psychrometric process for the CC and the EW+CC are presented in Figure 2. Observe the dramatic reduction in the CC load, approximately 40%, when

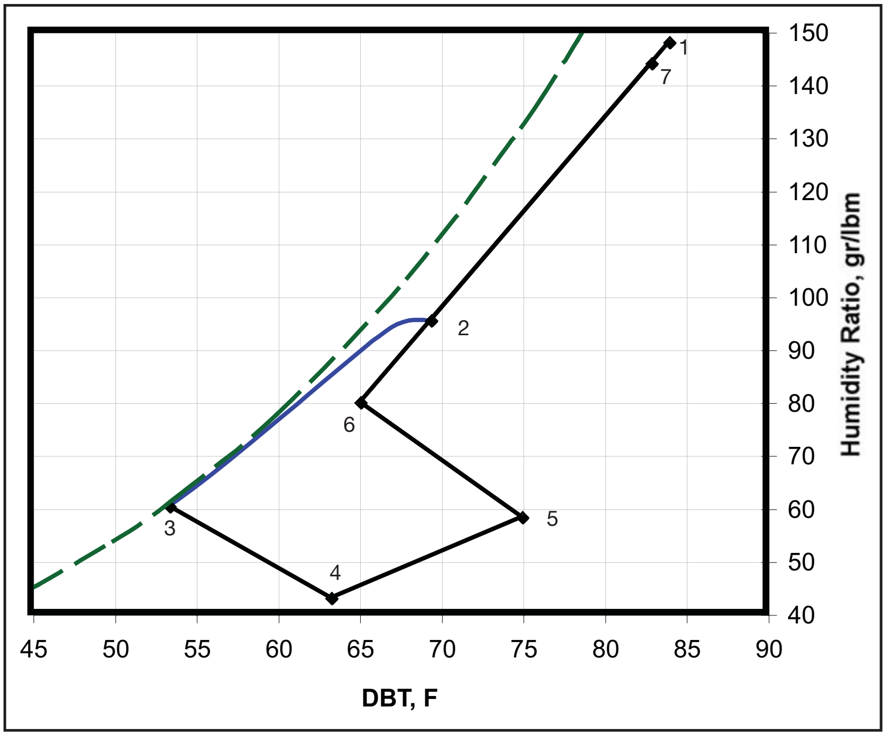
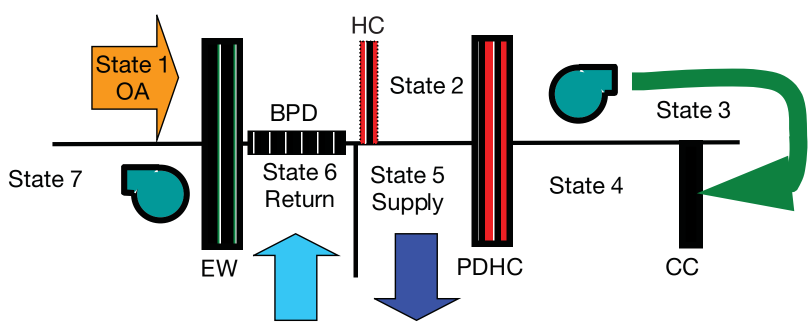


FIGURE 8. EW+CC+PDHC psychrometric chart.



State #	1,OA	2	3	4	5, Supply	6, Return	7
DPT, ˚F	84	78	76	50	54	75	82
W, gr/lbm	148	91	98	51	43	58	129

FIGURE 9. A second arrangement of PDHC and CC with EW (EW+PDHC+CC).

the EW is added. Adding a SW to the EW+CC arrangement allows the supply air temperature to be higher than the coil leaving temperature when the sensible loads are low.

Figure 3 illustrates the psychrometric process for the combined EW+CC+SW. Perhaps not obvious at first inspection, is that the reduction in the CC load is not as great as the lost SA sensible cooling due to a less-than-unity EW effectiveness. As a result, any time the SW is operating and a parallel system is providing sensible cooling in the space, the total cooling load on the plant is higher than if the SW were not operating.

PASSIVE DEHUMIDIFICATION COMPONENT CLASS

When low SA DPTs (less than about 48°) are required, they can be achieved with normal DX or chilled water CC operating temperatures with the aid of a passive dehumidification component (PDHC). The PDHC consists of a type III desiccant wheel, whose performance is characterized in Figure 4. Notice that the PDHC exhibits its maximum moisture holding (removal) capability when the entering air % rh approaches 100%, typical of the condition leaving a CC. Conversely, when the entering air % rh drops below 80%, the ability of the PDHC to hold moisture drops rapidly.

If the % rh of the reactivation air is too high for the desired rate of transfer, a heating coil can be used to reduce the % rh, thus increasing moisture transfer rates.

One arrangement of these components serving the DOAS market is illustrated in Figure 5. One hundred percent OA enters the PDHC where moisture is added to the airstream in an endothermic reaction nearly adiabatically, causing the air/water vapor mixture temperature to drop anywhere from 3° to 9°. The air/water vapor mixture is further cooled and dehumidified with the CC operating at conventional temperatures (leaving air temperatures of 50° to 55°). Finally, the 100% OA enters the other side of the PDHC where moisture is removed in an exothermic reaction, thus elevating the leaving air temperature 3° to 9°. The moisture removal is sufficient to lower the leaving air DPT by up to 10° below the CC leaving air DPT.

One manufacturer's psychrometric performance of the PDHC+CC equipment for a demanding cooling day, OA is 84° DBT, 148 gr/lbm is presented in Figure 6. Notice that the design condition taxed the system. Conditions were simulated with the manufacturer's software for preheat from zero to 19°. Only the 5.5° preheat is presented in this article. Increasing the preheat, resulted in increased cooling coil loads, elevated SA temperatures, and ever increasing preheat energy input.

INTEGRATED EW, PDHC, AND CC DEHUMIDIFICATION CLASS

Continuing the development of classes of equipment aimed at DOAS dehumidification, consider adding TER to the PDHC+CC equipment class. Two currently available pieces of packaged DOAS equipment that integrate EW, PDHC, and CC are illustrated in Figures 7 (EW+CC+PDHC) and 9 (EW+PDHC+CC), along with thermodynamic state point conditions (for a demanding cooling day, OA is 84° DBT, 148 gr/lbm) as determined by respective manufacturers' selection software.

The main difference between the two packages is the order and use of the PDHC. The state points for these packages are also presented psychrometrically in Figures 8 and 10 respectively. In these examples, both packages produced 43° SA DPTs but different SA DBTs of 63.3° and 54°, respectively. Significantly, the DBT leaving the CCs

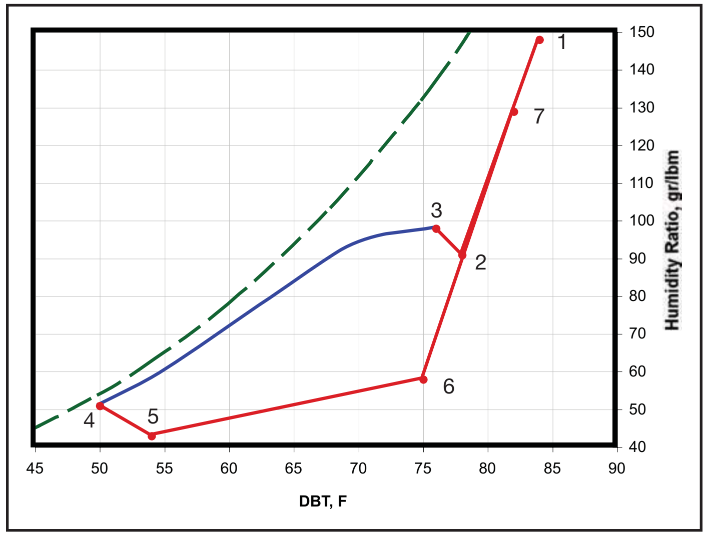
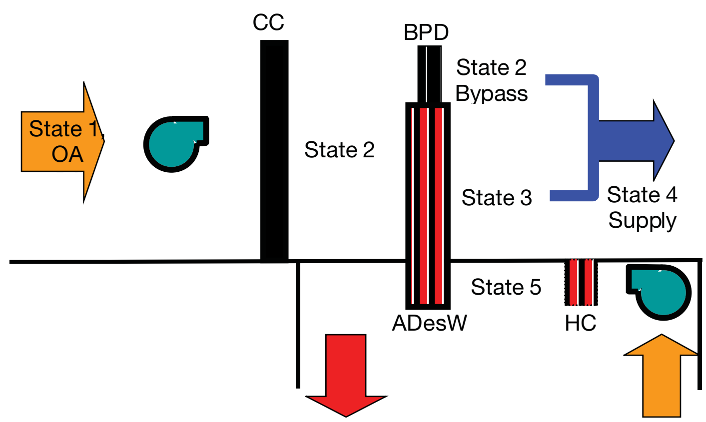


FIGURE 10. Psychrometric chart depicting EW+PDHC+CC.



State #	1,OA	2	3	4, Supply	5
DPT, ˚F	84	59.5	108	88.5	215
W, gr/lbm	148	75	24	43	161

FIGURE 11. Active desiccant wheel and CC arrangement.

(53.4° and 50°, respectively) is achievable with conventional DX and chilled water CC temperatures. The CC load for the EW+CC+PDHC system is 20 tons, and 25.5 tons, for the EW+PDHC+CC system.

However, the EW+CC+PDHC system SA delivers 4.6 tons less sensible cooling than the EW+PDHC+CC system. When the extra sensible cooling needed at the terminals for the EW+CC+PDHC system is added, the performance of the two systems is nearly equivalent — differing by about 1 ton; with the EW+PDHC+CC system requiring about 5% more load in this example.

The psychrometric processes for the PDHC (points 3 to 4 and 5 to 6 in Figure 8 and 2 to 3 and 4 to 5 in Figure 10) reflect the nearly constant enthalpy trends typical of a desiccant (rotating very slowly — less than one rpm), as opposed to that of a TER device, rotating at about 20 rpm. Placing the CC before the PDHC as in Figure 7, allows the CC to operate at a warmer temperature and less load while maximizing the moisture transfer

Arrangement #	Description	CC load, tons	SA DPT, ˚F	Lost sensible cooling, ref. arr.1	Total cooling input	Wheels total ΔP, in wg	Ranking, partly subjective
1	CC alone	48	44	0.0	48	0	5
2	EW+CC	27.8	44	0.0	27.8	0.57+0.43:	1
3	EW+CC+SW Figure 1	19.8	68	10.8	30.6	.073+0.49+0.43+).56: 2.21 total	4
4	PDHC,+CC Figure 5	48.3	53.1	4.1	52.4	0.71+0.71 1.43 total Preheat input: 30 MBh	6
5	EW+CC+ PDHC. Figure 7	20	63.3	8.7	28.7	0.24+0.23+0.29+0.29: 1.06 total	1
6	EW+PDHC+ CC. Figure 9	25.8	53	4	29.8	0.89+0.72+0.93+0.93: 3.77 total	3
7	CC,+ADesW Figure 11	34	88.5	20	54	Regeneration heat input: 234 MBtu	7

TABLE 1. Energy demand for various DOAS arrangements conditioning 100% OA from 84˚F DBT, 148 gr/lbm$_{DA}$ to 43 gr/lbm$_{DA}$ SA conditions.

Location	Miami	Hou	Shre	Ft.W	Atl	DC	St.L	NY	Chi	Port
Humidity Control (Occ Hours > 65% rh)										
Base DX	20	14	2	1	0	1	0	0	0	0
DX W/ AdesW	0	0	0	0	0	0	0	0	0	0
DOAS w/AdesW+DX	0	0	0	0	0	0	0	0	0	0
DOAS w/ EW+DX	0	0	0	0	0	0	0	0	0	0
Annual % Increase Or Decrease In Operating Cost Vs. Base DX										
DX w/ AdesW	52%	23	18	12	9	1	-2	1	-8	-1
DOAS w/AdesW+DX	48%	18	14	8	8	-3	-5	-6	-14	-8
DOAS w/ EW+DX	-18%	-21	-20	-19	-19	-23	-26	-19	-26	-14
LCC: Equipment 1st + 15 yr Gas and Electric $, 1,000's 2004 dollars										
DX w/ AdesW	51	45	43	45	40	44	41	59	41	38
DOAS w/AdesW+DX	54	48	46	48	44	47	45	63	45	42
DOAS w/ EW+DX	35	35	33	37	33	37	35	52	37	36

TABLE 2. 6,000-sq-ft, single-story office facility humidity control and annual operating cost compared to a base DX cooling system.

Location	Miami	Hou	Shre	Ft.W	Atl	DC	St.L	NY	Chi	Port
Humidity Control (Occ Hours > 65% rh)										
Base DX	1713	961	610	314	150	165	220	82	59	0
DX W/ AdesW	0	0	0	0	0	0	0	0	0	0
DOAS w/AdesW+DX	0	0	0	0	0	0	0	0	0	0
DOAS w/ EW+DX	0	1	6	0	0	0	0	0	0	0
Annual % Increase Or Decrease In Operating Cost Vs. Base DX										
DX w/ AdesW	169%	79	75	47	61	18	14	6	-11	-2
DOAS w/AdesW+DX	137%	53	44	20	20	-9	-11	-14	-30	-15
DOAS w/ EW+DX	-39%	-42	-41	-42	-41	-51	-54	-44	-55	-28
LCC: Equipment 1st + 15 yr Gas and Electric $, 1,000's 2004 dollars										
DX w/ AdesW	322	250	235	226	210	209	189	247	174	148
DOAS w/AdesW+DX	313	245	228	220	203	205	189	242	174	153
DOAS w/ EW+DX	88	91	90	104	92	100	90	138	100	106

TABLE 3. 79,000-sq-ft, single-story retail facility humidity control and annual operating cost compared to a base DX cooling system.

with the PDHC. Wrapping the PDHC around the CC, as in Figure 9, requires a lower CC discharge air DBT and increases the load thereon. The moisture removal capabilities of the PDHC are less in this arrangement than with the Figure 7 arrangement. But since the SA DBT leaving the PDHC is lower than the Figure 7 arrangement, it is able to do more sensible cooling.

INTEGRATED ACTIVE DESICCANT WHEEL / COOLING COIL DEHUMIDIFICATION CLASS

This class of dehumidification is especially well suited for applications where return air is not available for energy recovery, and where SA DPTs below about 50° are desirable. One commercially available arrangement is illustrated in Figure 11. Outdoor air is initially cooled and partially dehumidified with a CC. A portion of that air is then deep dehumidified with the active desiccant wheel (ADesW), which is reactivated with air at over 200°. The dehumidified air leaving the ADesW at 108° and 24 gr/lbm is mixed with the air at the CC leaving temperature, which by passed the ADesW, in a ratio that is delivered to the space at 88.5° and 43 gr/lbm.

The psychrometric performance of the OA as it passes through this unit is illustrated in Figure 12. This particular packaged unit is not adequate for the example illustrated in the article. The manufacturer offered that a custom unit could be built to better suit the conditions of the example. Beside the large CC load and the extra terminal cooling added with the hot SA DBT, it uses 234,000 Btuh of regeneration heat energy. While this is quite different than advertised, it is not unlike the findings of an ASHRAE-sponsored research report to be presented later in this article.

ENERGY DEMAND COMPARISON BY CLASS AT PEAK OA LATENT CONDITION

On the basis of the equipment and conditions presented above, the following energy demand was computed and presented in Table 1, when 5,000 cfm of 100% OA at 84° and 148 gr/lbm was dehumidified to 43 gr/lbm.

There are many considerations when ranking the different arrangements. The ranking system used is based upon simplicity, the probability of wasteful terminal reheat at the given SA DBTs, and subjective first and operating costs.

The author's top choice for cases where low SA will not cause terminal reheat to be necessary is arrangement 2, EW+CC, with arrangement 5 very close behind. The top choice for cases where low SAs will cause considerable terminal reheat is arrangement 5, EW+CC+PDHC.

ASHRAE RESEARCH RESULTS RELATED TO SOME CLASSES IN 10 GEOGRAPHIC LOCATIONS

The ASHRAE research project final report, 1254-RP, "Evaluating The Ability Of Unitary Equipment To Maintain Adequate Space Humidity Levels, Phase II," is the result of cooperative research between the ASHRAE, and GARD Analytics, Inc.[3]. Space does not permit all of the results to be presented (the final report is available online

Location	Miami	Hou	Shre	Ft.W	Atl	DC	St.L	NY	Chi	Port
Humidity Control (Occ Hours > 65% RH)										
Base DX	7091	5406	4077	3579	3083	2451	2529	1767	1577	4
DX W/ AdesW	1861	1211	620	162	22	7	208	0	13	0
DOAS w/AdesW+DX	2	18	0	0	0	0	0	0	0	0
DOAS w/ EW+DX	1104	516	130	33	0	0	49	22	0	0
Annual % Increase Or Decrease In Operating Cost Vs. Base DX										
DX w/ AdesW	173%	84	77	51	65	24	21	13	-4	1
DOAS w/AdesW+DX	217%	116	100	72	80	33	30	33	9	11
DOAS w/ EW+DX	56%	39	30	29	24	-2	-5	11	-5	9
LCC: Equipment 1st + 15yr Gas and electric $, 1000's 2004 dollars										
DX w/ AdesW	6	5	4	4	4	4	4	6	4	3
DOAS w/AdesW+DX	8	6	6	6	6	6	5	8	6	5
DOAS w/ EW+DX	5	5	4	5	4	5	4	7	5	4

TABLE 4. 350-sq-ft, hotel room humidity control and annual operating cost compared to a base DX cooling system.

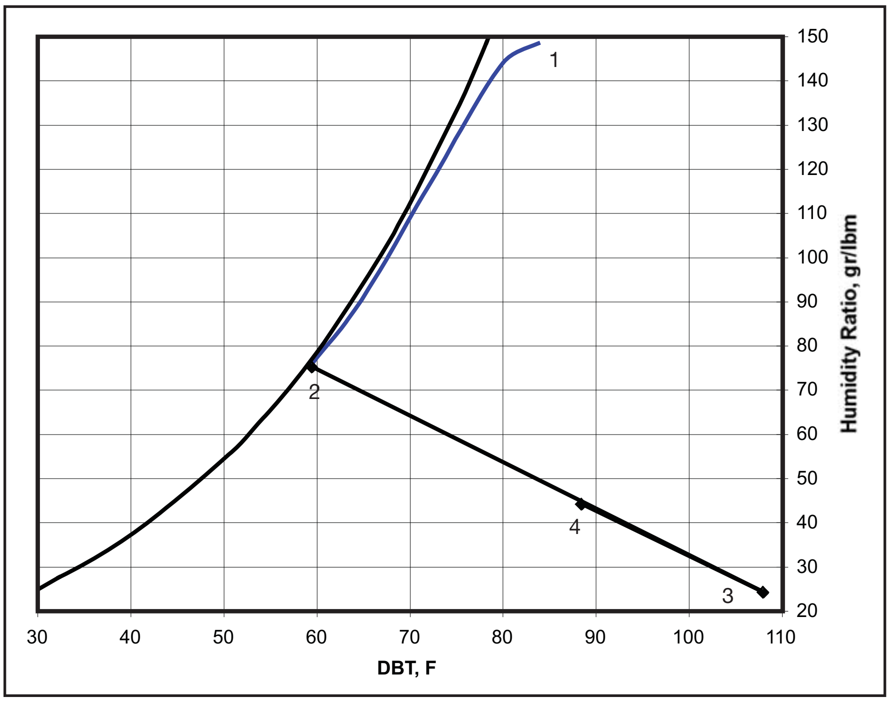


FIGURE 12. Psychrometric chart depicting active dehumidification.

at the link in the references). The ASHRAE research did not analyze systems utilizing PDHCs. The modeled airflow rate per ton of cooling ranged from 300 to 400 cfm/ton of cooling, corresponding to saturated SA temperatures of 48° and 52°, respectively.

The terminology used in Tables 2 through 4, DOAS w/ADesW + DX and DOAS w/ EW+DX recognizes that the DOAS is not capable of providing all of the space cooling due to the low ventilation airflow rates, and requires a parallel cooling system — DX in the research project. The base DX and the DX w/ADesW were each sized to satisfy the entire space loads.

Clearly, humidity control, annual operating costs, and LCC for DOAS w/ EW+DX are superior for office and retail applications. The results did not favor DOAS w/ EW+DX for the 350-sq-ft hotel room with respect to room humidity control; otherwise, it did well. The poor humidity control is a reflection of improper system sizing for the analysis, rather than an innate inability of the DOAS to control humidity. Where high latent generation is present relative to occupancy, either the rate of ventilation air must be increased or the SA DPT dropped.

CONCLUSIONS AND RECOMMENDATIONS

Providing the correct ventilation and space % rh for the purpose of achieving good IAQ can be ensured with DOAS systems. There are many DOAS components and arrangements, with some better able to meet the space % rh than others. Since the SA DPT and flow rate are the critical factors used to limit the maximum space % rh, they are the chief performance parameters of importance. The SA DPT in some instances must be below 50°. As the SA DPT requirement decreases, desiccant components become attractive tools that permit the CC temperatures to remain near normal (around 45°).

The reliable availability of desiccant based EWs is also an extremely useful tool for the engineer's toolkit, since integrating it with the CC allows major reductions in both the OA latent load and the chiller design capacity. For most commercial and institutional applications, the arrangements that employ EW+CC or EW+CC+PDHC seem to offer the best balance between IAQ and LCC. **ES**

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