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advances in Desiccant-Based Dehumidification

Unlike "cold-coil" dehumidification, which removes moisture from the air by condensing it on a cold surface, desiccant dehumidification relies on adsorption or absorption. This *EN* reviews recent advances in the application of desiccant dehumidification in commercial and institutional buildings.

An introduction to desiccants

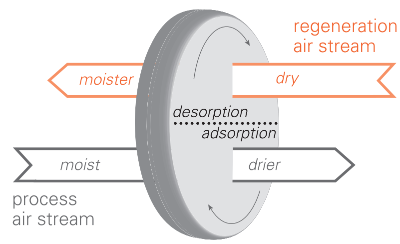
Desiccants are substances that attract water-vapor molecules from the air via an adsorptive or absorptive process.

Adsorption refers to a desiccant that does not change phase as it collects airborne moisture. Most adsorbents are solids; familiar examples include activated alumina, silica gel, and zeolites (molecular sieves). In *absorption*, collecting moisture changes the desiccant physically or chemically. Most absorbents, such as solutions of lithium chloride or triethylene glycol in water, are liquids.

There are literally hundreds of desiccants, each designed and manufactured for a specific task. They can be categorized by their ability to attract and hold water vapor at specific temperatures and relative humidities. The curve depicting this trait is a *desiccant isotherm*. Figure 1 shows typical isotherms for the Type I, Type II, and Type III desiccants that are often used for HVAC applications.

Adsorbents, or "solid" desiccants, are the focus of this article. Their most common application is the *desiccant wheel*, a cylindrical matrix of channels that are coated with or constructed from a solid desiccant. To maximize moisture collection, the wheel rotates slowly—only 10 to 30 rotations per *hour*—through two air streams (Figure 2).

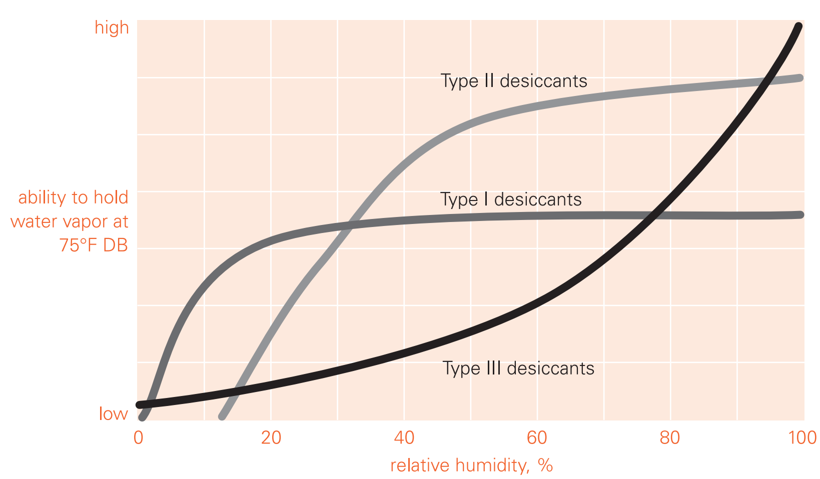
Figure 2. "Solid"-desiccant dehumidification wheel



"Process" air passes through one section of the wheel. Desiccant on that section adsorbs water vapor, making the air drier than when it entered. Wheel rotation then exposes the moisture-laden desiccant to a "regenerating" air stream that strips the captured moisture away from the desiccant (desorption).

Moisture transfer is enabled by the difference in vapor pressures at the desiccant surface versus the air passing over it. The desiccant collects

Figure 1. Typical desiccant isotherms



moisture when the surface vapor pressure is lower than that of the passing air, and releases it when the surface vapor pressure is higher. For practical purposes, since relative humidity (RH) is a function of vapor pressure, the direction of moisture transfer can be characterized by the difference between the relative humidities of the process and regeneration air streams.

The desiccant can retain little moisture when the regeneration-air RH is low, so water vapor will migrate from the desiccant to the regeneration air. When the RH of the process air is high, the desiccant can adsorb more moisture from that air stream. Maintaining an adequate difference between the relative humidities of the process and regeneration air streams is essential to dehumidify effectively using a desiccant wheel.

Note: Total-energy wheels, also known as "enthalpy wheels," perform differently than solid-desiccant dehumidification wheels; see inset (p. 5).

Traditional arrangements for parallel regeneration

Wheel upstream of cooling coil. Traditional parallel arrangements of desiccant dehumidification wheels use Type I or Type II desiccants and rotate between two discrete air streams (Figure 3). The regeneration air stream may be the building exhaust or a second outdoor air stream that's used solely to "regenerate" (reactivate) the desiccant. A heat source raises the dry-bulb temperature of the regeneration air, lowering its relative humidity. As a result, water vapor transfers from the higher-RH process air (OA) to the lower-RH regeneration air (RG').

However, the relative humidity of the air leaving the process side of the wheel (OA') can only get as low as the relative humidity of the air entering the regeneration side (RG'). The lower that the regeneration-air RH is, the lower the resulting process-air RH can be. Depending on the desired dryness, regeneration-air temperatures can range from 150°F to 300°F—hot enough that a gas-fired burner is typically used for this purpose.

In HVAC applications, desiccant wheels were historically used to dehumidify outdoor air brought indoors for ventilation. Figure 4 shows an example of wheel performance in this application, where a second, dedicated, outdoor air stream regenerates the desiccant.

A desiccant wheel removes moisture from the process air stream—but for every Btu of latent heat (moisture) removed, it adds more than one Btu of sensible heat. That is, air leaving the process side of the wheel (OA') is dry (at a low dew point) but hot (145°F DB in our example). Therefore, most applications include a cooling coil downstream of the wheel to recool the process air.

Due to the costs of regeneration and recooling, traditional desiccant wheels typically are used only when the required process-air dew point can't be achieved with standard mechanical equipment. (These costs become even more prohibitive as the price of natural gas rises.)

Figure 3. Desiccant dehumidification wheel *upstream* of cooling coil, parallel regeneration

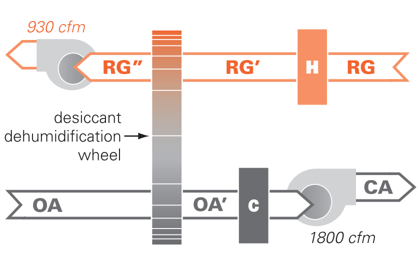
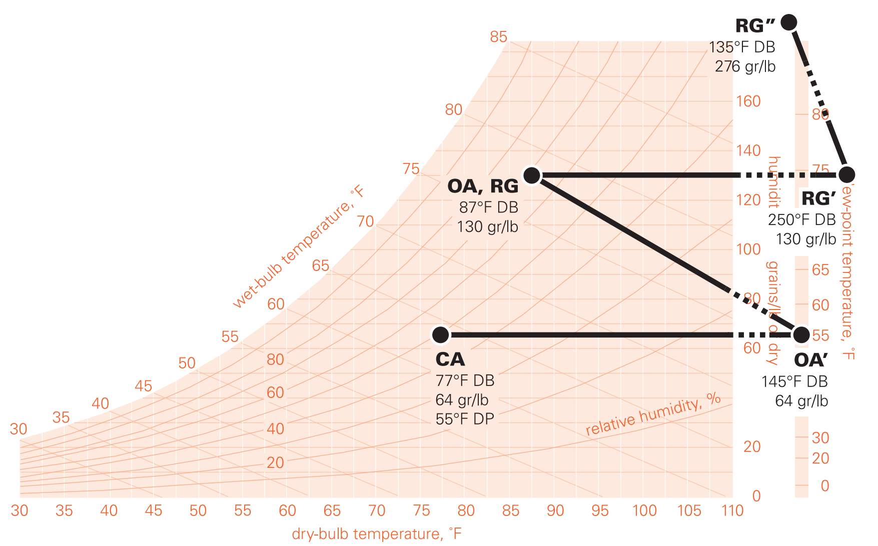


Figure 4. Performance example: Desiccant dehumidification wheel *upstream* of cooling coil, parallel regeneration (dedicated outdoor-air application)



Wheel downstream of cooling coil. One reason for the inefficiency of traditional desiccant systems is that the components are asked to perform at less-than-optimal conditions. A finned-tube cooling coil is most effective when wet, but the process air leaving the wheel requires only sensible cooling (so the coil is dry).

Desiccant performance suffers, too. Here's why:

- *Most desiccants adsorb more water vapor as the relative humidity of the process air rises*. While the RH of entering outdoor air varies widely during the cooling season, the RH of the air leaving an active cooling coil typically exceeds 90 percent. Therefore, the highest relative humidity in the system is directly downstream of an active cooling coil.
- *Most desiccants adsorb more water vapor as the dry-bulb temperature of the process air falls*. Again, the temperature of entering outdoor air varies significantly. But during the cooling season, the coldest temperature in the system is directly downstream of an active cooling coil.

Now, many systems are configured with the desiccant wheel *downstream* of the cooling coil (Figure 5), rather than upstream, to better apply the operating principles of cooling coils and desiccants. In this configuration, the process air (OA) first passes through a DX or chilled water cooling coil, where it's cooled and dehumidified. Then the cool, saturated air (CA) passes through the desiccant wheel, which adsorbs moisture from the high-RH air—lowering the dew point but raising the dry-bulb temperature. The resulting conditioned air (CA′) is dry and warm—but not as hot as in the "wheel upstream" configuration (Figure 3) described earlier. Water vapor transfers from the desiccant to the regeneration air (RG′) as the wheel rotates into the regeneration air stream.

Today, the "wheel downstream" configuration is most commonly used in dedicated outdoor-air applications, where the outdoor air is dehumidified to a low dew point and then delivered at a neutral dry-bulb temperature, either directly to the occupied spaces or to other local HVAC units. In the example shown in Figure 6, the "wheel downstream" configuration dehumidifies the process air to 55°F DP, while warming it to 77°F DB—roughly "neutral" compared to the space. The separate regeneration air stream is heated to 114°F DB to lower its RH and dry out the desiccant.

Compared with the "wheel upstream" arrangement, the "wheel downstream" configuration can dehumidify the process air to an equally low dew point and requires less recooling—perhaps none—because the leaving dry-bulb temperature isn't as hot. But it still requires a separate regeneration air stream, and that air typically must be heated to dry out the desiccant. The opportunity to regenerate the desiccant at a lower temperature means that heat from the condensing process of refrigeration equipment can be used for this purpose.

Figure 5. Desiccant dehumidification wheel *downstream* of cooling coil; parallel regeneration

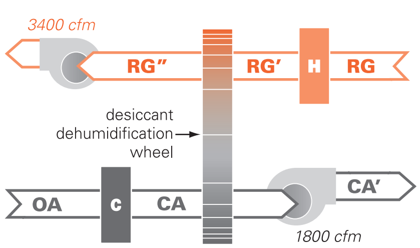
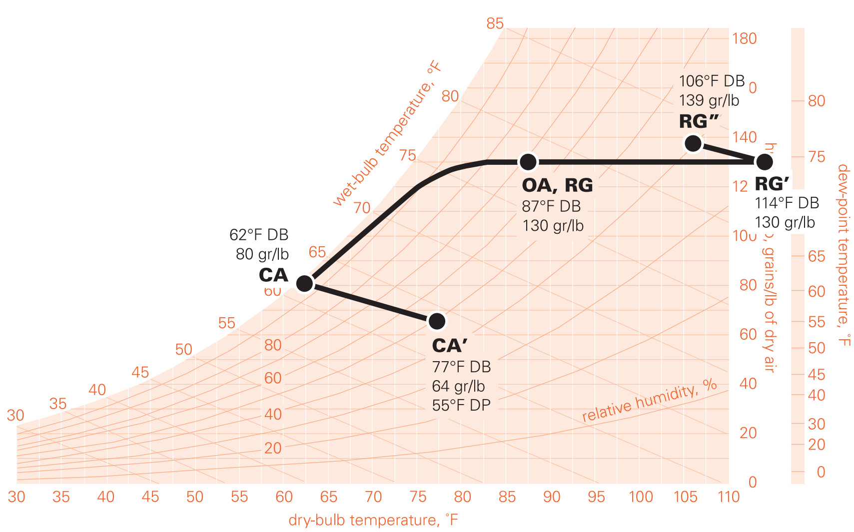


Figure 6. Performance example: Desiccant dehumidification wheel *downstream* of cooling coil, parallel regeneration (dedicated outdoor-air application)



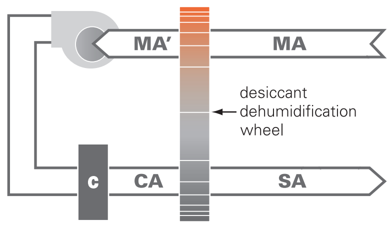
A different approach: Series regeneration

The latest advance in desiccant-based dehumidification places the desiccant wheel *in series* with the cooling coil (Figure 7), with the regeneration side of the wheel upstream of the cooling coil and the process side downstream of the coil. Moisture transfer occurs within a single air stream: The series desiccant wheel adsorbs water vapor from the process air downstream of the cooling coil and then releases the collected moisture upstream of that coil, allowing the cooling coil to remove it through condensation. A separate, regeneration air stream isn't needed.

The series desiccant wheel uses a Type III desiccant selected specifically for this application. The desiccant's ability to adsorb water vapor is very high when the relative humidity of the air is high (Figure 1, p. 1); when the RH is below 80 percent, its moisture-holding ability drops significantly. Recall that air leaving an active cooling coil often exceeds 90 percent RH; at this condition, the series desiccant wheel can adsorb lots of water vapor from the air. When the wheel rotates upstream of the cooling coil, it's exposed to air with a lower relative humidity (typically 40 to 60 percent). At this condition, the desiccant can't retain the water vapor that it collected, so the moisture transfers from the wheel to the passing air stream.

Adsorption isn't driven by hot regeneration air but by the Type III desiccant's ability to regenerate at low temperatures, often without supplemental heat. The design of the wheel and its rotation speed are engineered to maximize the transfer of water vapor while minimizing sensible-

Figure 7. Desiccant dehumidification wheel *downstream* of cooling coil, series regeneration

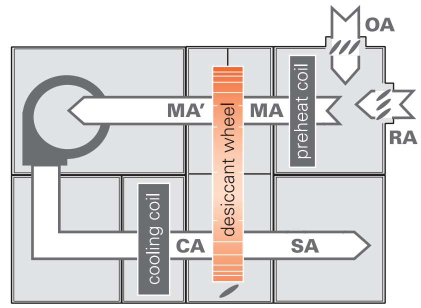


heat transfer. The increase in the dry-bulb temperature of the process air is associated only with the amount of heat produced by the adsorption process.

Series desiccant wheel in a mixed air application. Air leaving the process side of a series desiccant wheel is cooler than the space, not neutral or warmer. This makes the wheel suitable for use in the mixed air stream—and allows a single unit to both comfort-cool and dehumidify the space.

Figure 8 shows an example of a mixed-air air handler with a series desiccant wheel. The desiccant adsorbs water vapor from the air downstream of the cooling coil, enabling the system to deliver drier

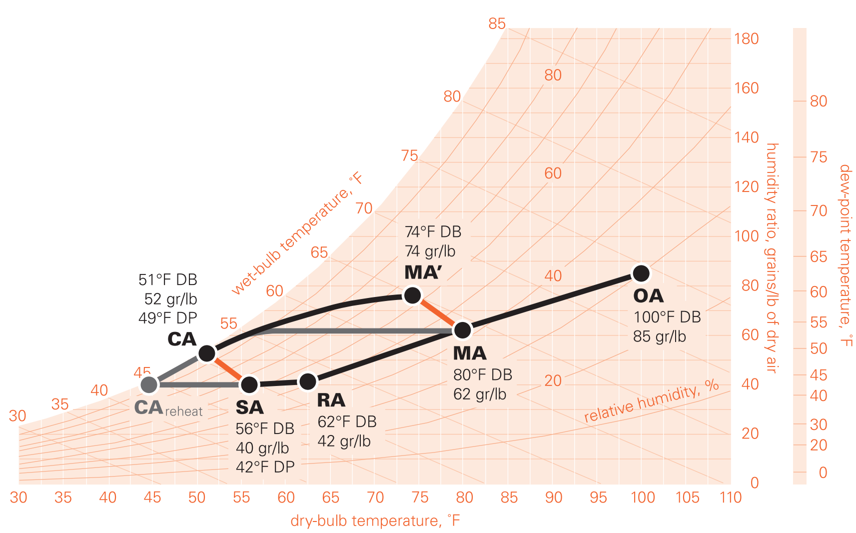
Figure 8. Desiccant dehumidification wheel (series regeneration) in a mixed air system



supply air (at a lower dew point) without lowering the coil temperature. The regeneration side of the wheel is located in the mixed air, upstream of the cooling coil. Because the RH of the air upstream of the coil is much lower than the RH of the air downstream, the adsorbed water vapor transfers upstream—and the cooling coil gets a second chance to remove the transferred water vapor via condensation.

Figure 9 shows the performance of this mixed air system in a surgery room. Air leaves the cooling coil (CA) at a high relative humidity. The series desiccant wheel adsorbs water vapor, drying the supply air (SA) to a dew point of 42°F (40 grains/lb). Sensible heat added by the adsorption process

Figure 9. Performance example: Desiccant dehumidification wheel *downstream* of cooling coil, series regeneration (mixed air application)



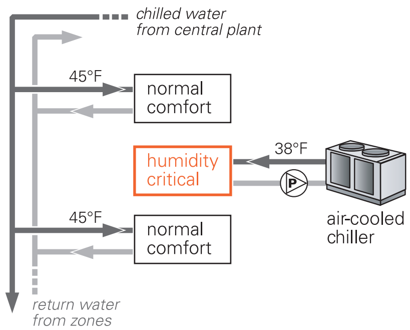
raises the supply-air temperature to 56°F DB.

Mixed air (MA) entering the regeneration side of the wheel is less humid, about 40% RH due to the low supply-air dew point in this example. At this RH, the wheel can no longer hold the water vapor it adsorbed downstream of the coil. Water vapor released from the wheel passes into the mixed air (MA') and then condenses on the cold coil surface.

Basically, adding the series desiccant wheel changes the dehumidification performance of the traditional cooling coil, trading sensible capacity for more latent capacity. The latent (dehumidification) capacity of the cooling coil increases while the total cooling capacity (enthalpy change across the coil) remains the same.

To deliver the same supply-air (SA) condition using a traditional "cool+reheat" system, the cooling coil must cool the air to nearly 42°F DB to achieve 42°F DP (CA_{reheat}). Then the reheat coil must raise the dry-bulb temperature to 56°F (Figure 9). By

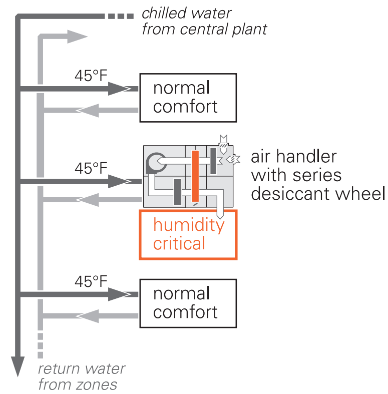
Figure 10. Dedicated chiller for humidity-critical zones



contrast, the series desiccant wheel can deliver the same dew point using fewer tons, no reheat, and with a warmer leaving-coil temperature (51°F vs. 42°F DB). This warmer coil enables more efficient mechanical cooling (a higher suction temperature in DX equipment, warmer water or a lower flow rate in chilled water systems).

A preheat coil can be added upstream of the regeneration side of the wheel (Figure 8) for applications that require even drier air. Activating the preheat coil raises the dry-bulb temperature slightly (5°F to 20°F) and *lowers* the

Figure 11. Air handler with series desiccant wheel for humidity-critical zones



relative humidity of the mixed air (MA). Lowering the relative humidity allows the desiccant to reject even more water vapor to the regeneration air, thus enabling it to adsorb more water vapor from the process air. In many cases, the modest amount of heat added by the preheat coil can be recovered from the condensing process of the refrigeration equipment.

Infrastructural side benefits. Comparatively few spaces in a typical building (or campus of buildings) require supply air with a lower-than-normal dew point. For example, a hospital houses surgery rooms, certain laboratories, and pharmacy prep areas that may require supply air at 35°F to 50°F DP. But patient rooms, waiting rooms, office spaces, cafeterias, and service areas seldom need such dry supply air.

Let's revisit the surgery-room example (Figure 9). The existing central chiller plant supplies the cooling coil with 45°F water, which isn't cold enough to produce the 42°F supply air needed using a conventional "cool+reheat" system. A common solution is to install a dedicated, stand-alone chiller that delivers colder fluid than the central plant currently produces (Figure 10).

However, if each of the air handlers serving the humidity-critical spaces includes a series desiccant wheel, the required 42°F DP can be achieved with

Total-energy (enthalpy) wheels

The construction of a total-energy wheel (also known as an "enthalpy wheel") is similar to that of a solid-desiccant dehumidification wheel. Its channel surfaces are coated with or constructed from a solid desiccant (adsorbent), and the wheel rotates between the outdoor and exhaust air streams. But the performance of a total-energy wheel is dramatically different due to its rapid rotation—20 to 60 rotations per *minute* versus 10 to 30 rotations per *hour* for a desiccant dehumidification wheel.

Basically, the total-energy wheel acts as a simple heat and mass transfer device. When it's hot and humid outside, the wheel carries sensible heat and moisture (latent heat) from the outdoor air to the cooler, drier exhaust air. When it's cold and dry outside, the wheel carries sensible heat and moisture from the warmer, more humid exhaust air to the outdoor air.

Total-energy wheels can significantly reduce ventilation cooling and heating loads, especially at peak conditions, but they do *not* dehumidify the space. Think of it this way: If the wheel is 100 percent effective, the outdoor air leaving the supply side of the wheel can only get as dry as the exhaust air entering the other side. And the exhaust air comes from the space. Therefore, if the wheel is 100 percent effective, the outdoor air leaving the wheel can become as dry as—*but no drier than*—the space. If the supply air is no drier than the space, it can't *dehumidify* the space. The system still requires a cooling coil (or some other device) to make the supply-air dew point lower than the dew point in the space.

Total-energy wheels allow downsizing of cooling, dehumidifying, heating, and humidifying equipment, and reduce the energy associated with these processes. However, the additional pressure drop increases fan energy use, and most of the building exhaust air must be ducted back to pass through the exhaust-side of the wheel. (For more information, see Trane manual SYS-APM003-EN, available from www/trane.com/bookstore/.) •

51°F DB air leaving the cooling coil. If sufficient capacity is available at the central plant, proper cooling coil selection could allow the existing 45°F water to produce 51°F air leaving the coil, thereby eliminating the need for a separate chiller (Figure 11, p. 5).

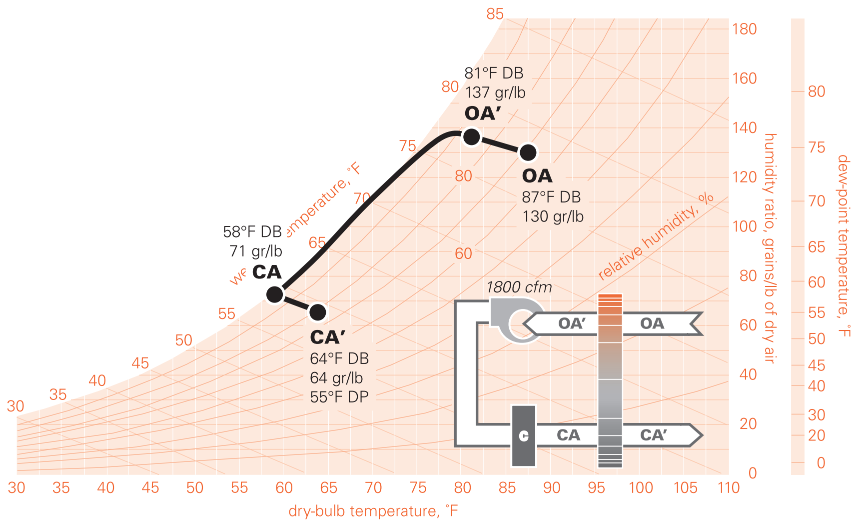
Series desiccant wheel in a dedicated outdoor-air application. The series desiccant wheel can be used in dedicated outdoor-air applications, too. Because the series desiccant wheel adds very little sensible heat to the process air, it raises the dry-bulb temperature (CA') only slightly.

Figure 12 shows such a system operating at the same conditions as the "wheel downstream with parallel regeneration" example in Figure 6 (p. 3). A comparison of psychrometric performance shows that the series regeneration arrangement delivers conditioned air that's not only as dry (55°F DP) as, but also much cooler (64°F DB versus 77°F DB) than, the conditioned air delivered by the "wheel downstream with parallel regeneration" arrangement. Note, too, that at this condition, supplemental regeneration heat is unnecessary for the series arrangement.

For most applications, whenever possible, *the dedicated outdoor-air unit should be designed to deliver the air cold—not warmed to neutral.* Delivering cold conditioned air takes advantage of the sensible cooling already performed by the cooling coil in the dedicated outdoor-air unit.

This design strategy may require more cooling capacity at the dedicated outdoor-air unit, but the cooler supply air offsets some of the space cooling loads, allowing the local HVAC units to be smaller, quieter, and less expensive (Table 1). In most dedicated outdoor-air applications, the spaces won't be overcooled by delivering the outdoor air cold until the sensible load in the space drops significantly. Consider using communicating controls to determine

Figure 12. Performance example: Desiccant dehumidification wheel *downstream* of cooling coil, series regeneration (dedicated outdoor-air application)



when a space is at risk of overcooling, and limit use of reheat to those times.*

When the relative humidity of the entering outdoor air is high (on a mild rainy day, for example), it may be necessary to preheat the air entering the regeneration side of the series desiccant wheel in order to lower its relative humidity. Typically, the amount of heat is small and it may be required for only a few hours. Therefore, it may be practical to recover the needed heat from the condensing process of the refrigeration equipment. (A small, inexpensive electric heater is another option.)

Alternatively, a total-energy wheel can be added to the system (Figure 13). When high RH conditions occur, the total-energy wheel will transfer moisture from the entering outdoor air (OA) to the exhaust air (EA), thus

* See *Engineers Newsletter* volume 30-3, "Design Tips for Effective, Efficient Dedicated Ventilation Systems," available online at http://www.trane.com/commercial/library/vol30_3/enews_30_03.pdf.

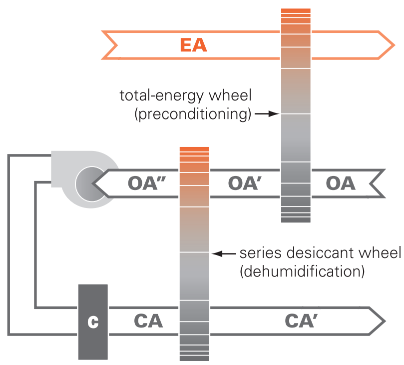
Table 1. Performance comparison: Parallel vs. series desiccant wheel[a]

	Parallel configuration (Figures 5, 6)	Series configuration (Figure 12)
Dedicated outdoor-air unit		
Supply-air dew point	55°F DP	55°F DP
Supply-air dry bulb	77°F DB	64°F DB
Cooling capacity	**8.6 tons**	**10.7 tons**
Leaving-coil temperature	62°F	58°F
Regeneration heat	**100 MBh**	**0 MBh**
Local HVAC terminals		
Cooling capacity	**15.0 tons**	**12.9 tons**
Supply airflow	**6,000 cfm**	**5,200 cfm**
Total system		
Total cooling capacity	23.6 tons	23.6 tons

No regeneration heat required. Added cooling capacity at the dedicated outdoor-air unit helps offset space cooling load, enabling smaller local HVAC terminals

[a] Dedicated outdoor-air application without energy recovery. Process side of desiccant wheel is *downstream* of cooling coil. Parallel configuration requires a separate source of regeneration heat; series configuration does not.

Figure 13. Total-energy wheel preconditions outdoor air entering a dehumidifying series desiccant wheel



lowering the relative humidity of the air before it enters the regeneration side of the series desiccant wheel (OA′). In such cases, adding a total-energy wheel reduces (and often eliminates) the need to add regenerative heat. This gives the series desiccant wheel an advantage over the parallel regeneration arrangement.

Regardless of whether parallel or series regeneration is used, including a total-energy wheel will save both cooling and heating energy and offer the opportunity to downsize heating and cooling equipment. It may also be required by local energy codes or ASHRAE Standard 90.1.

When to consider using a desiccant

Mixed air systems. If the system provides both comfort cooling and dehumidification for the space, investigate the benefits of using a desiccant when the required supply-air dew point is below 50°F. Common applications are surgery rooms, laboratories, dry storage, archive rooms, museums, supermarkets, and many process applications.

- The series desiccant wheel can achieve a lower supply-air dew point without lowering the coil temperature. Unlike a system with a cooling coil alone, the supply-air dew point can be lower than the coil's surface temperature.
- The series desiccant wheel minimizes the addition of sensible heat, allowing it to supply cool air rather than warm—effectively meeting both the dehumidification (latent) and cooling (sensible) needs of the space.
- The series configuration requires only one air stream; a separate regeneration air stream is unnecessary.

Dedicated outdoor-air systems. For systems that dehumidify the outdoor air before delivering it directly to occupied spaces or to other local HVAC units, investigate the benefit of using a desiccant wheel:

- *when the conditioned outdoor air must be delivered at a neutral dry-bulb temperature*. But remember … Designing the dedicated outdoor-air unit to deliver the air cold, not neutral, takes advantage of the sensible cooling done by the cooling coil in the dedicated outdoor-air unit. This allows the local HVAC units to be smaller, quieter, and less expensive.
- *when the required dew point of the conditioned outdoor air cannot be achieved reliably with a traditional cooling coil alone*. However, the dew point that the dedicated outdoor-air unit must deliver often exceeds 48°F. (For guidance, see Trane manual SYS-APG001-EN.)

A series desiccant wheel dehumidifies the outdoor air to a low dew point, and then delivers it cool rather than neutral. Adding a total-energy wheel allows smaller-sized cooling, dehumidifying, heating, and humidifying equipment, and can reduce system energy use. It also reduces (or often eliminates) the need to add "regenerative" heat to the desiccant wheel when the relative humidity of the entering air is high. •

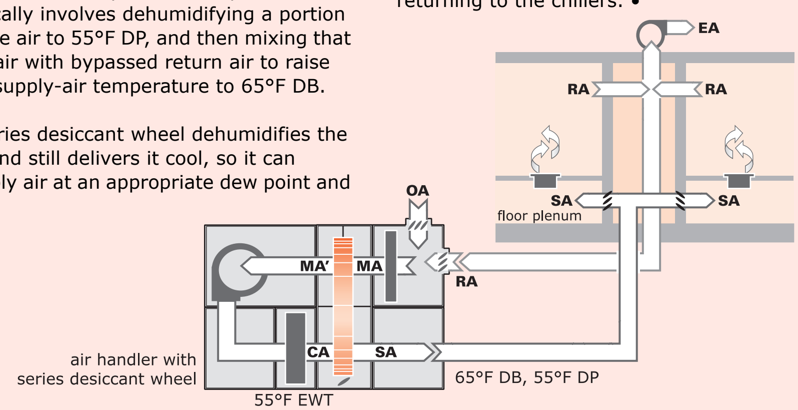
By John Murphy, applications engineer, and Brenda Bradley, information designer, both of Trane. You can find this and previous issues of the *Engineers Newsletter* at http://www.trane.com/commercial/library/newsletters.asp. To comment, e-mail us at comfort@trane.com.

The "series desiccant wheel" configuration described in this newsletter is marketed by Trane under the name CDQ™ (Cool, Dry, Quiet).

UAD and series desiccant wheels

Underfloor air distribution (UAD) systems usually distribute warmer air than traditional overhead systems—65°F versus 55°F, for example. When a UAD system is applied in a non-arid climate, the supply air first must be sufficiently dehumidified to avoid humidity problems in the space, and then warmed to a comfortable temperature. In practice, this typically involves dehumidifying a portion of the air to 55°F DP, and then mixing that dry air with bypassed return air to raise the supply-air temperature to 65°F DB.

A series desiccant wheel dehumidifies the air and still delivers it cool, so it can supply air at an appropriate dew point and dry bulb for a UAD application—and it does so with *a warmer leaving-coil temperature* (62°F vs. 55°F DB) than return-air bypass. In chilled water UAD systems, a warmer coil permits the use of warmer water (55°F, in this case) or an extremely low flow rate of cold water … perhaps even return water from other cooling coils in the system, allowing the same water to be used twice before returning to the chillers. •



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