PART 3 OF 3

DEHUMIDIFICATION ENHANCEMENTS
for 100-Percent-Outside-Air AHUs

Enthalpy heat exchange, the use of desiccants, and vapor-compression dehumidifiers are cost-effective ways to maintain healthy and comfortable buildings

By DONALD P. GATLEY, PE

Following an introduction to technology options for dedicated outside-air units (Part 1, September 2000) and a discussion of recuperative heat exchange, ordinary "new-energy" reheat, and reheat using hot refrigerant gas (Part 2, October 2000), this series concludes with coverage of exhaust-air/outside-air enthalpy exchange, heat-powered active desiccant dehumidification, and vapor-compression refrigeration-cycle dehumidification.

EXHAUST-AIR/OUTSIDE-AIR ENTHALPY EXCHANGERS

Exhaust-air/outside-air enthalpy heat exchange is a universal technology applicable to electricity-powered vapor-compression, direct-expansion, and chilled-water air-handling-unit (AHU) coils; heat-powered desiccant-dehumidification equipment; supermarket and ice-rink air-conditioning and dehumidification systems; and packaged 100-percent-outside-air conditioners.

Part 1 of this series suggested that the first step in achieving enhanced dehumidification that is cost-effective throughout the life cycle of a building is collecting as much building exhaust and relief air as possible and passing it through one side of an enthalpy heat exchanger with outside air on the other side.

There are two types of air-to-air enthalpy exchangers:

- Aluminum rotary-wheel heat exchangers, which are coated or impregnated with a desiccant.
- Flat-plate heat exchangers, which feature engineered composite resin plates that separate exhaust- and outside-air streams.

Aluminum rotary-wheel enthalpy heat exchangers often are found in built-up AHU systems and custom AHUs, while flat-plate enthalpy heat exchangers often are used in residential applications. These heat exchangers are similar in appearance (but not construction) to the sensible-energy heat exchangers featured in Part 2 of this series.

While the sensible-heat-transfer effectiveness of these two enthalpy energy exchangers is comparable, the latent-heat- (water-vapor-) transfer effectiveness is not, as flat-plate heat exchangers are less effective during the winter and even more so during the summer. A specially engineered mix of desiccant coatings on many enthalpy wheels allows rotary-wheel heat exchangers to transfer sensible and latent heat with nearly equal effectiveness during both the winter and summer.

The enthalpy heat exchanger is an energy-efficient dehumidification technology because it uses low-sensible-heat-, low-water-vapor-content exhaust air to transfer sensible heat and water vapor from makeup air during the cooling season. In doing so, the enthalpy heat exchanger is not the primary means of dehumidification, as another device must first establish a low dew-point temperature in the conditioned space and, therefore, the exhaust air. If the primary means of dehumidification is not furnished or activated at full- or part-load operating conditions, then the humidity level in the space will rise and the enthalpy exchanger will experience little or no success in its attempt to transfer water vapor.

Advantages. The main advantages of enthalpy exchangers are:

- During the summer, they transfer the "coolth" and low-moisture content of the exhaust air to the outside makeup air. This results in energy savings as well as reductions in moisture load and the size and cost of cooling equipment. In many cases, the addition of a properly sized enthalpy exchanger will allow a packaged air conditioner to handle outside-air loads well above the nominal 15 to 20 percent provided for in the manufacturer's design.
- During the winter, they transfer heat and moisture from exhaust air.
- There is no water, ethylene-glycol, or refrigerant charge.
- Enthalpy-wheel control is easy.
- There are no heat-transfer fluids that are subject to freezing.

Disadvantages. Possible disadvantages of enthalpy exchangers are:

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	ENTHALPY HEAT-EXCHANGE WHEEL	HEAT-POWERED DESICCANT WHEEL
Basic function	Energy recovery from exhaust air; sensible- and latent-heat transfer to or from return or exhaust air, to or from outside (makeup) air, or to a mixture of outside and return air.	Dehumidification, adsorption of water vapor from process-air stream,regeneration of desiccant.
Wheel design optimized for	The transfer of sensible and latent heat from one air stream to another.	The removal of water vapor from process air.
Construction*	Aluminum matrix with desiccant coating applied after fabrication of wheel.	Corrugated fluted ceramic matrix with desiccant impregnated during manufacture of wheel.
Typical 48-in. wheel	3436-cfm exhaust air at 600 fpm (50 percent) and 3436-cfm outside air at 600 fpm (50 percent); 7.87-in. depth; estimated desiccant mass: 60 lb.	5155-cfm process air at 600 fpm (75 percent) and 1718-cfm regeneration air at 600 fpm (25 percent); 15.74-in. depth; estimated desiccant mass: 230 lb.
Revolutions per hr	Typical: 1200; range: 700 to 2400.	Typical: 12; range: 4 to 20.
Maximum rotor temperature	Varies by product; 500 F typical; some as low as 180 F.	Varies by product; 1300 F for some, 275 F for others.
Side 1 (typical)	Outside air; 92 F, 120 grains (entering); 80 F, 76 grains (leaving).	Process air (enthalpy wheel upstream); 80 F, 76 grains (entering); 110 F, 40 grains (leaving).
Side 2 (typical)	Exhaust air; 77 F, 65 grains (entering); 89 F, 109 grains (leaving).	Regeneration air; 92 F, 120 grains (entering); 250 F (at burner exit).
Pressure drop	Side 1: 0.65-in. WG; Side 2: 0.65-in. WG.	Process side: 2-in. WG; regeneration side: 1.75-in. WG.
Longevity concerns	Contamination by particulate, oil vapors, alkali or acidic gases, salt air, etc.; damage or misalignment during shipping; seal wear or misalignment; drive failure.	Same as enthalpy wheel plus fracture of desiccant during regeneration cycle due to significant changes in temperature and moisture content.

*Not typical of all manufacturers.

TABLE 1. Comparison of enthalpy heat-exchange wheels and heat-powered desiccant wheels.

- A restricted physical arrangement of inlet- and outlet-air streams.
- They require 120-v, 60-cycle single-phase power for a fractional-hp motor.
- Although the Air-Conditioning and Refrigeration Institute is developing testing and rating standards, there is no policing program through which random verification tests are performed by an independent agency.
- Some enthalpy-wheel drive systems have proven to be unreliable, while others require high maintenance.
- The life of the heat- and moisture-transfer media may be shorter than that of other options.
- With enthalpy wheels, leakage between air streams reduces effective-air quality and performance and increases fan-air quantity and power. Although the initial leakage rate may be acceptable, the wearing or misalignment of circumferential, partition, or purge seals may result in increased leakage.
- Condensation may be detrimental to some types of rotors and media.
- At part-load space conditions, when the primary means of cooling and dehumidification is not fully active, humidity can rise significantly.
- Changes in the shape of large enthalpy wheels (called “wheel runout” or “warping”) may impact the performance and life of seals and lead to cross-contamination.

HEAT-POWERED ACTIVE DESICCANT DEHUMIDIFIERS

The wheels in heat-powered active desiccant dehumidifiers are somewhat similar in appearance to those in enthalpy heat exchangers. But active-desiccant-dehumidifier wheels are much deeper in the direction of air flow, are constructed of low-mass materials (not aluminum), contain significantly more desiccant, revolve at one-tenth the speed, and must be constructed to withstand thermal stresses ranging from low winter temperatures to regeneration temperatures of 300 F or higher. For a comparison of heat-powered desiccant wheels and enthalpy heat-exchange wheels, see Table 1.

Active desiccant dehumidifiers should be considered when dew-point temperatures below 45 F are required. Desiccant equipment often enjoys a life-cycle cost advantage at dew-point temperatures below 40 F because moisture is removed from the air without being condensed on cold surfaces.

With refrigeration-type dehumidifiers, on the other hand, coil surfaces are susceptible to frosting at dew-point temperatures of 40 F and lower. This complicates controls and requires defrosting components and an increase in compressor capacity to compensate for the loss in productive run time.

At dew-point temperatures above 45 F, the life-cycle costs of active desiccant dehumidification usually are higher than those of conventional cooling with recuperative reheat systems—except in areas with very high electricity-demand charges and low summer gas costs. Conventional cooling using recuperative reheat systems is simpler, easier to maintain, and often lower in life-cycle cost at dew points as low as 40 F. Another niche application for this technology is installations requiring 40-to-55-F-dew-point-temperature air at dry-bulb temperatures in the 100-to-130-F range.

A seldom-discussed limiting characteristic of active desiccant dehumidifiers is that most wheels have been designed for a maximum removal of 45 to

60 grains of water vapor per lb of dry air passing through the process side of the desiccant wheel. This maximum rating is achieved at the lowest cataloged face velocity of a given wheel diameter and the highest regeneration temperature. Thus, with an entering-air dew-point temperature of 75 F (132 grains of water vapor per lb of dry air), the lowest possible leaving dew-point temperature is 58 F (72 grains of water vapor per lb of dry air), which results in higher-than-desired relative humidity (RH) in the space. If the entering dew-point temperature exceeds 75 F, then the space dew-point temperature and RH will be even higher. The solution to this is to either collect exhaust air and use an upstream enthalpy heat-transfer wheel or use a precooling coil upstream of the desiccant wheel to lower the entering temperature. This has a significant effect on the performance of the desiccant.

As the process air (the air to be dehumidified) contacts the desiccant, the latent heat of the air is converted to sensible heat. The water-vapor content of the leaving air is depressed and, as a simple conservation-of-energy equation shows, the leaving-air temperature increases at least 6.31 F for every 10 grains of water vapor absorbed. A significant portion of this sensible heat, along with heat retained in the desiccant (and wheel structure) from the high-temperature regeneration process, then is removed by run-around coils, heat pipes, flat-plate heat exchangers, heat-recovery wheels, indirect evaporative-cooling heat-transfer elements, or a combination of these.

> Desiccant technology has been used in industrial applications for decades; however, there have been problems with the design, selection, installation, operation, and maintenance of newly introduced or redesigned desiccant equipment and systems.

Obviously, the overall energy effectiveness of the desiccant-dehumidification cycle is improved when a major portion of the sensible heat is removed without the use of chilled water or refrigerated cooling. If a desiccant dehumidifier is applied upstream of an existing air conditioner without the use of heat pipes, a heat-recovery wheel, and/or another low-energy means of removing 100-F-plus heat from the process-air stream, then the net load on the air conditioner will be greater than that of an installation without a desiccant dehumidifier, resulting in overall energy costs that are significantly higher than those of a cooling coil with a recuperative enhancement (see Part 2).

Desiccant must be continuously regenerated through heating to drive out adsorbed water vapor. Overall energy effectiveness of the regeneration section is improved with heat exchangers, heat-recovery wheels, or heat pipes and the use of waste heat from engines (jacket water and/or a heat exchanger in the exhaust), refrigerant hot gas, or other available sources. These low-temperature heat sources can displace a portion of the high-temperature energy required for regeneration. Higher-temperature energy sources are required for the last stage of regeneration.

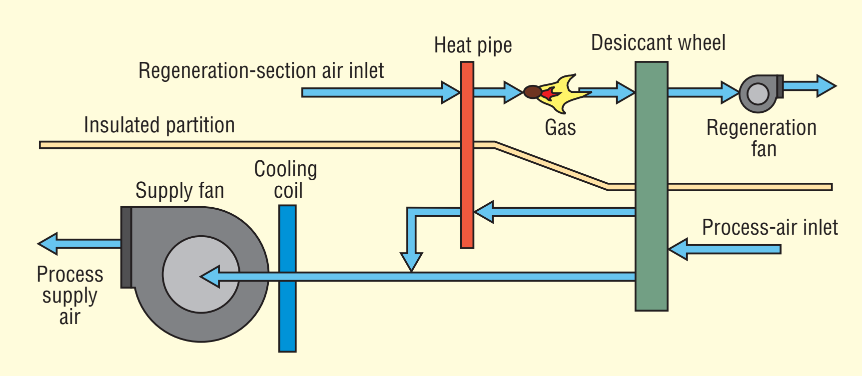

FIGURE 1. Desiccant-dehumidification cycle using a heat-pipe heat exchanger.

Figure 1 shows a desiccant-dehumidification cycle using a heat-pipe heat exchanger that transfers some heat from the process air leaving the desiccant wheel to the regeneration air stream upstream of the regeneration heater.

Desiccant technology has been used in industrial applications for decades; however, there have been problems with the design, selection, installation, operation, and maintenance of newly introduced or redesigned desiccant equipment and systems. The Gas Research Institute, the National Renewable Energy Laboratory, and some manufacturers continue to research and develop new desiccants, equipment, and systems, seeking improved efficiencies, lower air-pressure drops, lower reactivation temperatures, and longer life. Because the quality of equipment may vary considerably by manufacturer, the following should be carefully considered:

- Desiccant life and performance.
- Air-pressure drops through the wheel media and required filters.
- Whether the media can be cleaned without changing desiccant performance.
- If a lithium-chloride desiccant is used, the release of lithium chloride from the wheel under high-humidity conditions may result in corrosion of support media, hardware, casings, motors, drives, or downstream ductwork (most commercial units now use a silica-gel desiccant for this reason).
- The wheel bearings and drive mechanism (belts, chains, gears, or direct), including variable-speed control if it is used.

- The type of seals between air streams and at the wheel periphery, the availability of replacement seals, and the ease and frequency of replacement.
- Cross-leakage between air streams as cataloged; as installed; and after one, two, and five years of operation.
- Odors from some desiccant wheels during daily startup.
- The lifetime of the media and wheel.
- The availability of replacement media, wheels, etc. and access for service and replacement.
- The temperature of regeneration as cataloged, as installed, and after several years.
- Safety controls.
- Operating controls, particularly those that minimize thermal input at part-load conditions.
- The quality of design and construction; the reputation of the manufacturer; and application, startup, troubleshooting, and service assistance from the manufacturer.
- If a purge-air segment is used to minimize cross-contamination and/or achieve lower leaving dew-point temperatures, its impact on performance and maintenance.

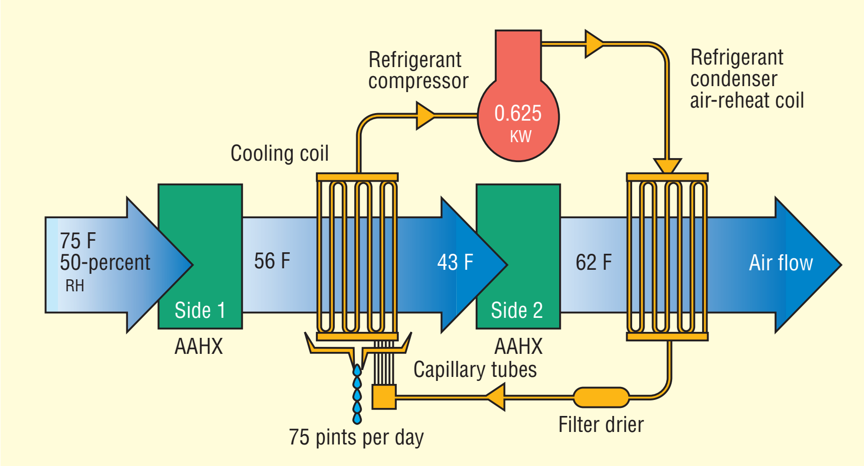

FIGURE 3. Enhanced recuperative-cycle dehumidifier.

There are several experienced manufacturers whose commercial desiccant equipment satisfactorily addresses each of these concerns.

VAPOR-COMPRESSION DEHUMIDIFIERS

Until recently, all dehumidifiers utilized the simple arrangement of a refrigerant coil followed by a hot-gas condenser reheat coil (Figure 2). With this arrangement, leaving air is dryer and much warmer than entering air. Table 2 illustrates the thermodynamic balance of the dehumidifier.

The net sensible-heat addition to the space is the sum of the latent heat of the condensed water vapor and the compressor- and fan-motor-energy inputs, all in consistent units.

At least two manufacturers offer dehumidifiers with recuperative enhancements as illustrated in Figure 3. One uses an air-to-air heat exchanger, while another uses a heat pipe.

Table 3 compares the performance of five medium- and small-size dehumidifiers. The units with recuperative heat exchangers utilize less power than do the simple-cycle dehumidifiers. Also, they reject less sensible heat to the space. This is particularly important in an air-conditioned facility during the cooling season because the air conditioner will consume additional energy in removing the dehumidifier sensible-heat addition to the space.

Designers and purchasers are cautioned to select dehumidifiers based on actual entering-air dry-bulb temperature and RH. Years ago, the industry standardized "nominal" rating conditions, with entering air at 80 F and 60-percent RH. Under typical operating conditions, room air may be in the 75-F, 50-percent-RH range; however, in subgrade rooms, it may be in the 60-F, 60-percent-RH range. Reductions in capacity are specific to each manufacturer. Some units may suffer significant capacity reductions at 60 F and 60-percent RH because of frosting of the evaporator.

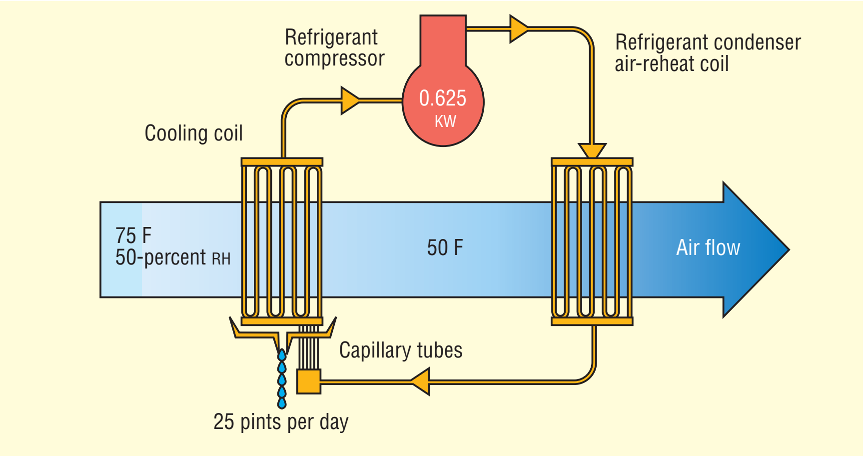

FIGURE 2. Conventional dehumidification cycle.

Heat extraction at evaporator coil		Heat rejection at condenser coil
Sensible cooling	=	Sensible heating
Latent cooling (moisture removal)	=	Converted to sensible heating
	+	Sensible heating from compressor energy
	+	Sensible heating from fan energy

TABLE 2. Dehumidifier thermodynamic balance.

Type	Pints per day at 80-F DB, 60-percent RH	Dehumidifier only KWH per pint	Dehumidifier only EER latent	Dehumid Plus 10 EER A.C. net KWH per pint	Dehumid Plus 10 EER A.C. net EER latent
Recuperative air-to-air HX	100	0.15	7.48	0.31	3.58
Recuperative heat pipe	200	0.24	4.58	0.43	2.55
Non-recuperative industrial	120	0.25	4.45	0.44	2.49
Non-recuperative residential	40	0.36	3.03	0.60	1.84
Non-recuperative industrial	140	0.42	2.62	0.67	1.63

Notes:
- Condensed water 1100 Btuh latent heat per pint.
- Author's interpretation of manufacturer's data. Readers should not rely on data in this table for buying comparisons. Manufacturers may use different rating methods and laboratories. Independent laboratory certification recommended.
- EER equals latent heat removed per watts input.
- Net KWH per pint and EER incorporate the additional electrical power used by an EER 10 air-conditioning unit to remove the dehumidifier sensible-heat rejection.

TABLE 3. Dehumidifier performance.

Often, dehumidifiers are purchased based on capacity and price without regard for operating cost. Using the net-KWH-per-pint data in Table 2, the cost of removing 6000 pints of water per year at 8 cents per KWH varies from \$148 to \$322. This \$174 difference in annual operating cost can justify the investment of an extra \$400 to \$800 in a more-efficient dehumidifier. More-efficient, higher-cost dehumidifiers are quieter and may be integrated into an existing duct system.

OTHER MEANS OF IMPROVING EFFICIENCY

Other means of improving the overall effectiveness of high-latent-capacity air conditioners and dehumidifiers include the use of high-efficiency compressors, high-efficiency motors, and an optimized heat-transfer surface. If an air-conditioning system utilizes return air, then the options of cooling-coil-face and return-air (not mixed-air) bypass and dual-path cooling coils (one for outside air and one for return air) will improve latent effectiveness. Another way to enhance system efficiency is to reduce cooling- and heating-coil face velocities by increasing coil face area and reducing row depth. With a significant reduction in the hp required to move air through the coil, a large-face-area, three-row coil can perform essentially the same cooling function as a small-face-area, six-row coil.

CONCLUSION

This series of articles was written to inform owners, designers, and contractors about cost-effective options for delivering dehumidified air to buildings to minimize or eliminate indoor-air-quality problems and provide comfort that can lead to optimum productivity. ■