The Impact of Relative Humidity, Heat of Adsorption and Carry-over Heat

White paper

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Perhaps the simplest and best way to describe the thermodynamic performance of the SEMCO Passive Dehumidification wheel is to compare it to a traditional active desiccant dehumidification wheel. Both wheels have a supply air (process) side which is dehumidified and heated as well as a regeneration side which leaves the process cooled and humidified, carrying away the moisture removed from the supply air stream.

In an active dehumidification wheel, a small regeneration airstream with typically a high absolute moisture level (outdoor air) is heated to an elevated temperature, generally between 200 and 300 degrees Fahrenheit. Heat is added to lower the relative humidity of this "regeneration" airstream since the desiccant moisture capacity changes as a function of the partial pressure of moisture in air divided by the saturation pressure or Relative Humidity. When the entering supply air (higher relative humidity) comes in contact with the rotating desiccant wheel media which has reached near equilibrium with the low relative humidity regeneration airstream, it is both heated and dehumidified as moisture leaves the airstream and enters the desiccant on the surface of the wheel. The regeneration airstream is conversely humidified and cooled.

The temperature rise of the supply airstream leaving the desiccant wheel is associated with two factors: (1) Heat of adsorption and (2) wheel heat carry-over associated with the mass of the rotating wheel. Both topics are addressed later on in this document.

The SEMCO passive dehumidification wheel operates under the same fundamental thermodynamic principles as the active desiccant wheel described above, but with several distinct operational differences.

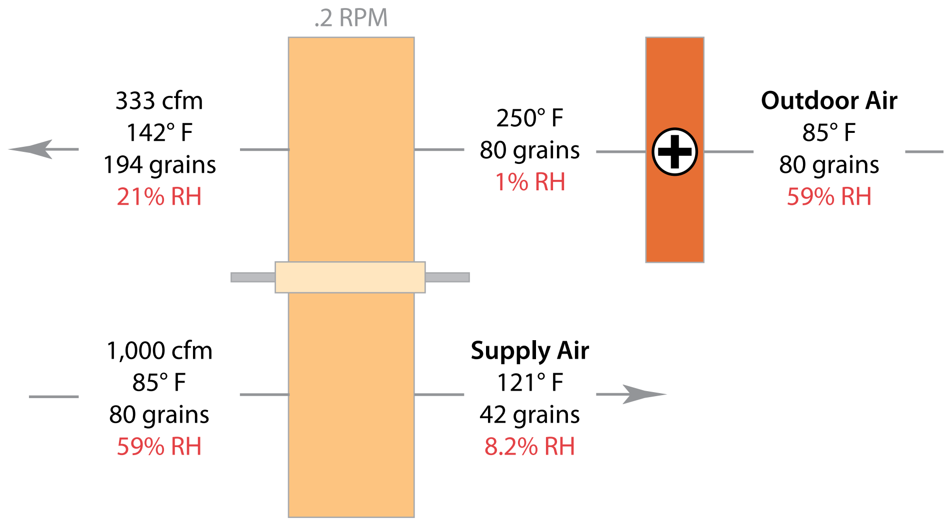

Figure 1. Sample active desiccant wheel performance.

The supply air entering the passive dehumidification wheel passes through a cooling coil to increase the relative humidity of the entering supply air to near saturation. Unlike the active dehumidification wheel, unheated return air from the building is used for "regeneration". The consistent space relative humidity, typically 50% and the saturated air leaving the cooling coil, typically 98% provide the driving force needed to deliver important dew point depression beyond that achieved by the cooling coil alone.

With the passive dehumidification wheel the return airflow is typically 60 to 90% of the supply airstream while the regeneration flow of an active desiccant wheel is usually only a small fraction (25 to 33%) of the supply airstream.

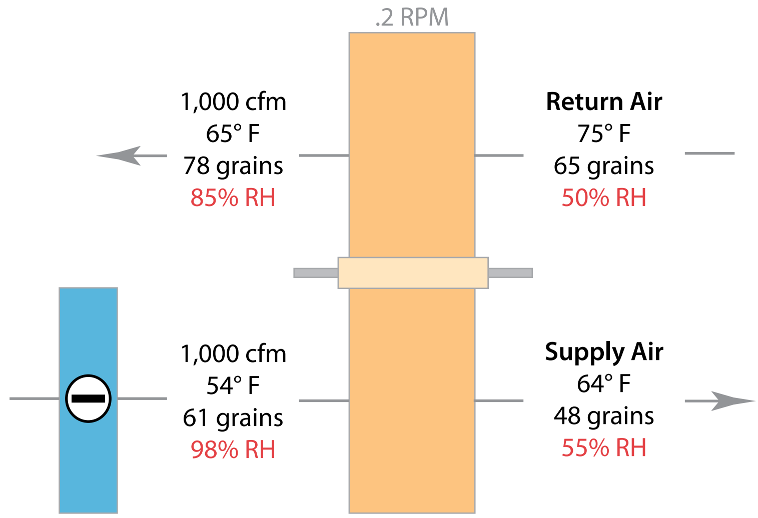

Figure 2 Sample SEMCO passive desiccant wheel performance.

Aside from these differences, the passive and active desiccant wheels perform the same function and are driven by the same thermodynamic principles. The obvious advantage of the passive wheel is that no regeneration energy is required. The advantage of the active wheel is that the high regeneration energy allows for more moisture to be removed (greater grain depression).

Heat of adsorption

As the moisture in the supply airstream is adsorbed onto the desiccant wheel, heat is released by the desiccant (heat of adsorption), thereby raising the temperature of the supply airstream as it passes through the wheel media. The supply air temperature leaving the desiccant wheel is further increased due to carry-over heat associated with the mass of the rotating wheel structure, and will be discussed separately within this document.

The amount of adsorption heat released and thereby supply airstream temperature rise due to moisture transfer is a direct function of the amount of moisture cycled. If less moisture is adsorbed, the adsorption temperature rise will be less and if there is more moisture adsorbed, the reheat will be more. Psychrometrically this means that the enthalpy level of the supply air leaving the desiccant wheel must always be somewhat higher than that entering the wheel and leaving the cooling coil.

This occurs because the heat of adsorption is greater than the latent heat of vaporization of water. The heat of adsorption is the sum of the latent heat of vaporization of water plus the heat of wetting on the desiccant surface. The heat of wetting will vary as a function of the saturation level of the desiccant. For comparison, the latent heat of vaporization of water is approximately 1,000 BTU/lb while the heat of adsorption for commonly used desiccant materials employed in active descant wheels range between 1100-1300 BTU/lb of moisture adsorbed.

The amount of adsorption heat associated with passive dehumidification wheels is somewhat less than exhibited by active wheels. Since near saturated air is entering the desiccant wheel and "regeneration" relative humidity levels are seldom below 45%, the heat of adsorption for the desiccant will be near its minimum, thereby only slightly higher (say 10%) than the latent heat of vaporization.

Figure 3 is a psychrometric plot of the data contained within Figure 2. It is provided as an example of proper thermodynamic presentation of performance associated with a high performing passive dehumidification wheel.

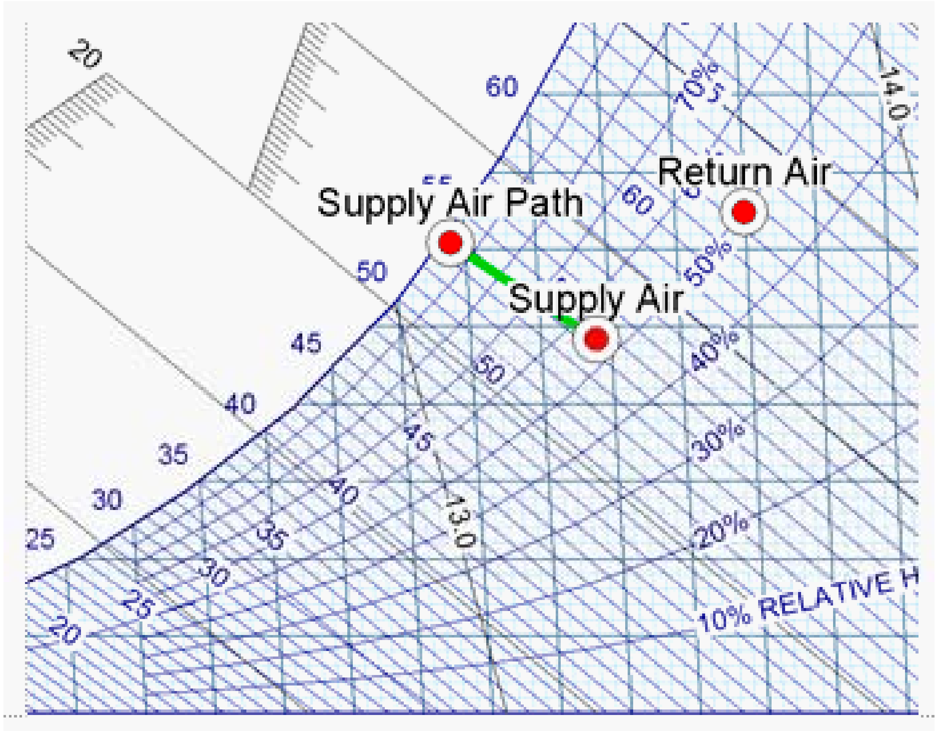

Figure 3. Showing proper psychrometric plot of passive dehumidification wheel performance.

If performance for an active or passive dehumidification wheel is shown with a supply air enthalpy level equal to or less than that leaving the cooling coil, it is shown incorrectly and thermodynamically impossible to achieve.

Carry-over heat

Since the mass of the desiccant wheel media is high relative to the mass of the air, even at very low wheel speeds (.2 to .4 rpm) some of the heat contained within the regeneration airstream will be transferred into the supply airstream as the wheel rotates from the regeneration/return airstream into the supply airstream. The increase in the supply airstream temperature associated with this carry-over heat is a function of the difference in temperature between the regeneration and the entering supply airstream, the rotational speed of the desiccant wheel and the ratio of the airflows (supply vs. return).

With active desiccant wheels using elevated regeneration temperatures, the carry-over heat can be considerable. Looking at the sample data shown within Figure 1, a regeneration temperature of 250°F is used. Given the large differential between the regeneration temperature and the outdoor air temperature entering the wheel, the carry-over heat raises the supply air temperature across the wheel by approximately 12 degrees. The heat of adsorption contributes the remaining 24 degree temperature rise to produce the 121°F supply air temperature shown.

Compared to an active desiccant wheel, the carry-over heat is considerable less for the passive desiccant wheel. Since the return airstream used for "regeneration" is always near 75 degrees and a typical leaving coil condition is near 55 degrees, only a 20 degree difference exists compared with 165 degrees for the active desiccant wheel. Using Figure 2 as an example, approximately 1.5 to 2 degrees of the temperature rise shown across the supply side of the passive desiccant wheel can be attributed to carry-over heat. The remaining temperature rise is associated with the heat of adsorption, previously discussed.

During the development of the Pinnacle system, SEMCO discovered that slight changes in the speed of the passive dehumidification wheel could be made to increase or decrease this carry-over heat while maintaining a desired supply air humidity level. The ability to modulate the supply air temperature to meet changing space loads is highly beneficial for dedicated outdoor air systems and is discussed in detail by the SEMCO technical bulletin entitled "Benefits Offered by Passive Dehumidification Wheel Speed Control".

As an example, consider the conditions presented as Figure 2. It is very common that a supply air temperature of 68 degrees rather than 64 degrees might be required to avoid overcooling spaces served by chilled beams. Increasing the supply air temperature at the same humidity level can be accommodated by slightly increasing the speed of the PD wheel. The higher speed provides more wheel mass relative to the mass of the air, resulting in more wheel carry-over heat while still allowing for effective dehumidification.

RH driver for Adsorption

As previously discussed, the moisture capacity of desiccant materials is a direct function of the partial pressure of moisture in air divided by the saturation pressure or Relative Humidity. When the entering supply air (higher relative humidity) comes in contact with the rotating desiccant wheel media which has reached near equilibrium with the lower relative humidity regeneration airstream, it is heated and dehumidified.

It is important to note that the factor limiting the supply air humidity level delivered by a well designed passive dehumidification wheel is the relative humidity of the return or regeneration airstream. In short, the near saturated air leaving the cooling coil can be dehumidified and heated, at a "near" constant enthalpy condition to a relative humidity that approaches, but not equal to that of the return airstream.

Figure 4. Showing proper (55% RH) and improper (48% RH) psychrometric plot of passive dehumidification wheel performance.

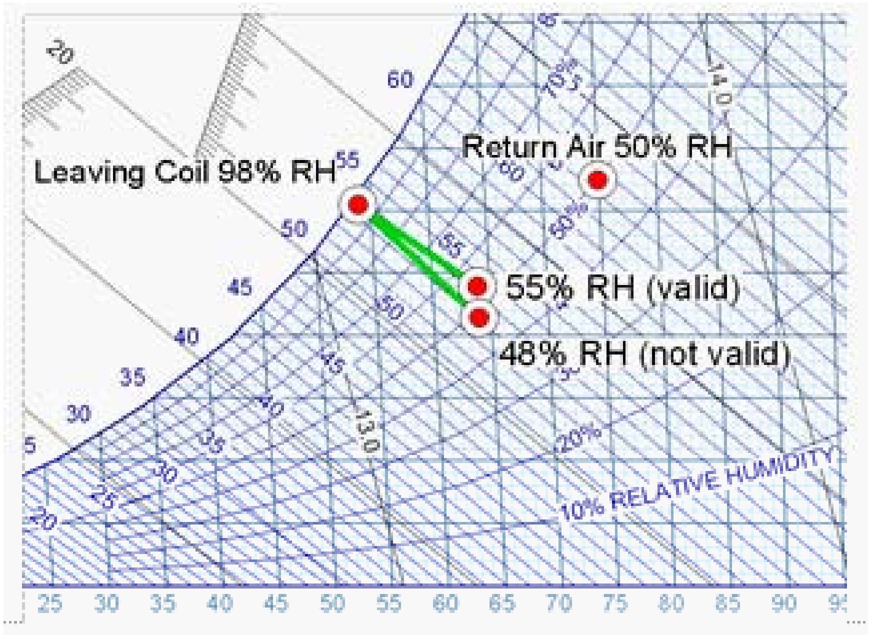

Figure 4 is provided to show valid psychrometric performance for a passive dehumidification wheel as compared to an invalid (thermodynamically impossible) performance. The valid point (a plot of Figure 2 data) shows the saturated air leaving the cooling coil dehumidified to a relative humidity (55%) that approaches, but does not reach, the return air relative humidity level and at an enthalpy slightly higher than leaving the cooling coil. This condition respects the thermodynamic principles associated with heat of adsorption and carry-over heat.

The invalid point plot, although similar in appearance, shows performance that cannot be achieved. First the supply air relative humidity (48%) is shown to be below that of the return relative humidity (50%). Secondly, the supply air enthalpy shown is less than that leaving the cooling coil. Neither of these conditions can exist. If such conditions are proposed, and they have been by some suppliers, they should not be considered since they cannot be achieved thermodynamically and a system with compromised dehumidification capacity will result.

Understanding the driving force for moisture adsorption is critical when choosing dedicated outdoor air systems integrating passive desiccant wheels. The SEMCO Pinnacle system has the advantage of using return air from the space for regeneration. Since the relative humidity of this airstream is always near 50%, the driving force for dehumidification is significant even as the outdoor air conditions vary widely. As a result, the performance shown in Figure 2, for example, is recognized whether the outdoor air is hot and dry (95°F and 100 grains) or mild and raining (75°F and 130 grains), when dehumidification is most needed.

Dedicated outdoor air systems employing the "wrap around" approach with passive desiccant wheels quickly lose the ability to provide effective dehumidification when the outdoor humidity level is high since the regeneration airstream used is preconditioned outdoor air leaving the total energy wheel, not the return airstream. As a result, whenever the outdoor air humidity is high (85°F and 125 grains) or in the 70's and raining, the relative humidity available for regeneration is 60% or higher. This subtle difference when compared to Figure 2 performance results in a very significant degradation of performance.

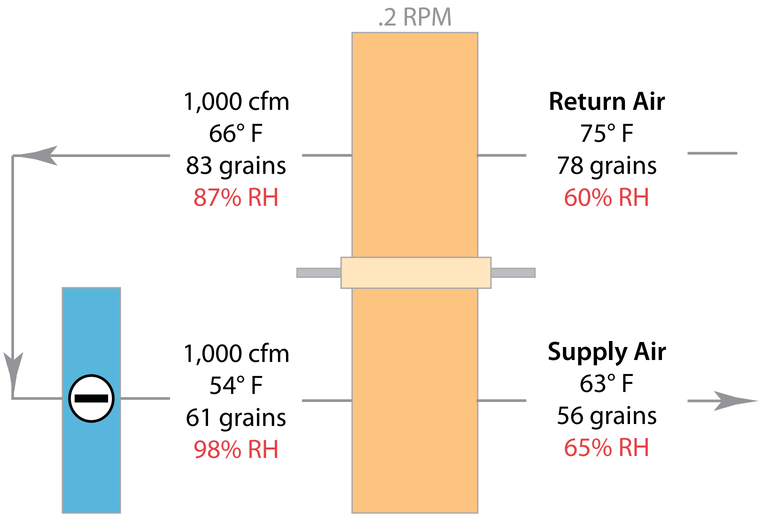

Figure 5. Sample "wrap around" passive desiccant wheel performance.

Figure 5 provides performance typical of a "wrap around" passive desiccant wheel employed in a dedicated outdoor air system when the outdoor air is cool and humid. Note that under identical leaving coil conditions the wrap around approach delivers only 56 grains of moisture versus 48 grains provided by the Pinnacle approach shown in figure 2. Assuming the typical 75°F at 50% RH target common for most design selections, the Pinnacle approach, using similar cooling tons, delivers 90% more dehumidification capacity than the wrap around approach ((65 grains – 48 grains)/(65 grains – 48 grains)). As a result, to handle the same internal latent load using the wrap-around approach during these conditions, 90% more airflow and the commensurate increase in cooling tons would have to be provided.

It is equally important to note that that the conditions where the air leaving the total energy wheel exceeds 60% relative humidity and when dehumidification is needed are frequent. They occur each morning when the outdoor temperatures are cool and humid, whenever it is raining and during warm days coincident with high humidity levels. In short, whenever humidity control is most needed.

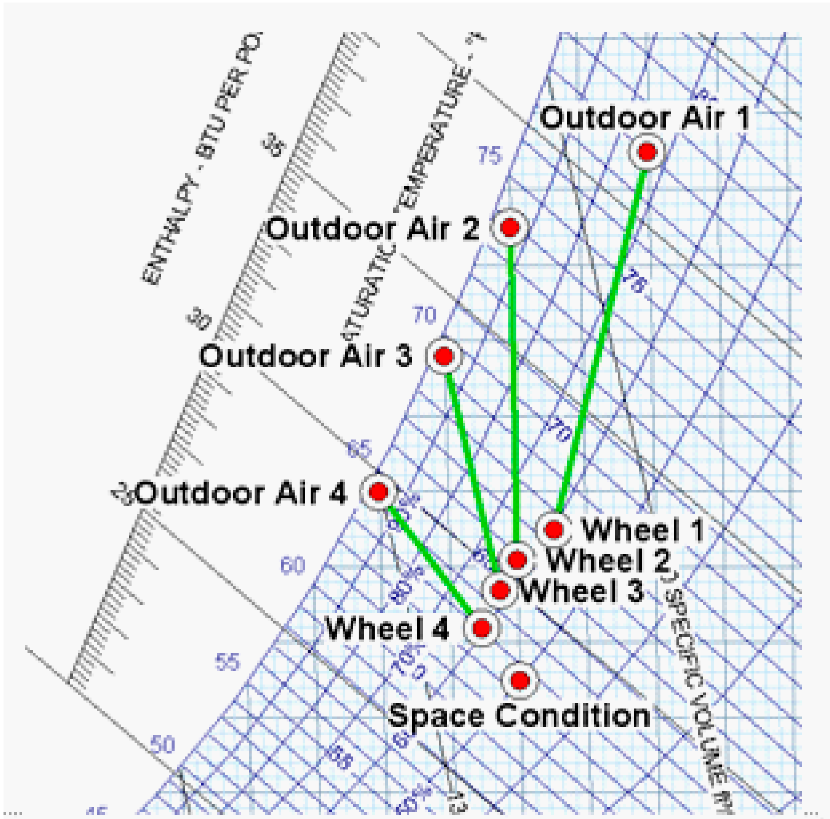

Figure 6. Supply conditions from a total energy wheel at various outdoor conditions.

Figure 6 is provided to show various outdoor air conditions that frequently occur during the cooling and dehumidification seasons. It assumes that the space is conditioned to 75°F at 50% RH and that this condition is exhausted from the building. An 81% effective total energy wheel processing 10% more supply airflow than exhaust is used.

The four conditions shown are (1) 85°F and 130 grains, (2) 75°F and 125 grains, (3) 70°F and 108 grains and (4) 65°F and 90 grains. The key observation to be made is that the resulting supply air conditions leaving the total energy wheel are all found to be between approximately 60% and 65% relative humidity.

As a result, the supply air humidity delivered by a wrap-around passive dehumidification wheel approach will often be compromised as a result of the elevated relative humidity of the regeneration airstream. Therefore, designs must be based upon the peak ASHRAE dew point design conditions and frequent part load conditions, not the peak sensible conditions often used by designers for selecting air cooled equipment.

Using the wrong design conditions will result in equipment selections that overstate the dehumidification capacity of wrap-around style systems yet prove substantially short during times of high humidity when latent capacity is needed most. As shown by the example comparing Figures 2 and 5, the wrap around approach might have only half of the dehumidification capacity at peak latent conditions provided at the peak sensible condition. If the total energy wheel used has a low latent performance, the resulting high regeneration humidity cuts capacity further.

In short, the dehumidification capacity provided by the "wrap around" passive desiccant wheel installed within a dedicated outdoor air system is variable and a strong function of the outdoor air humidity level. This must be carefully analyzed when selecting equipment utilizing this approach. The SEMCO Pinnacle approach which has the advantage of using return air as the regeneration source is very stable and thereby isolated from changes in outdoor air humidity swings.

What is the point?

With the growing popularity of "decoupling" building latent loads from sensible loads through the use of dedicated outdoor air systems as well as advanced air distribution technologies like chilled beams and displacement ventilation, more companies are offering systems incorporating passive desiccant wheels. Few companies have experience with these products and there are few suppliers of proven passive desiccant wheel components.

To avoid serious dehumidification performance deficiencies performance proposals for such systems must be carefully checked to be certain that the supply enthalpy from the passive desiccant wheel is not lower than that leaving the coil. It is equally important to make certain that the supply humidity content is not lower than possible given the relative humidity content of the regeneration airstream and that the selection has been made at ASHRAE peak dew point design conditions and not the peak sensible conditions, otherwise significant dehumidification capacity shortfalls will result.

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