

Dedicated Outdoor Air System Design and Operation

Avoiding Pitfalls

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Experience and Web-based trending and monitoring¹ of DOAS have revealed pitfalls primarily involving design decisions and operation of the control. This article discusses two pitfalls involving the enthalpy wheel and cooling coil.

Enthalpy Wheel Control Pitfalls

In an effort to provide simple controls, some engineers are choosing to operate the enthalpy wheel (EW) during all occupied hours. This approach, while common and simple, causes considerable unnecessary cooling energy demand and consumption.

Operating the EW when the outdoor air (OA) enthalpy is below the return air enthalpy unnecessarily increases the cooling coil (CC) load beyond loads it would experience with no EW. This is true for mild OA dry-bulb temperature (DBT) above and below the desired supply air temperature (SAT). For the latter case, operating the EW at full speed reduces or eliminates the ability to do free cooling with OA. Engineers need to be sensitive to this issue since DOAS often are criticized for an inability to provide airside, economizer-free winter cooling.^{2,3}

Other engineers use OA DBT control to determine the on-off mode for the EW (see *Figure 1*). This more advanced control approach does not require OA and return air (RA) enthalpy data, which is generally computed from temperature and relative humidity (RH) measurements. The absence of RH sensors simplifies the controls and eliminates their first cost and calibration attention requirements.

For the conditions when the outside air temperature (OAT) is slightly below 75°F (24°C) and near saturation, the enthalpy is more than 38 Btu/lb_{DA}. An enthalpy wheel with a total effectiveness of 85% would reduce the enthalpy of the OA entering the CC to about 29.5 Btu/lb_{DA} (only slightly higher than return air enthalpy). This represents more than 3 tons (10.5 kW) of cooling avoidance per 1,000 cfm (472 L/s) of OA—reducing energy use, demand and size/first cost of the cooling plant.

As noted previously for the simple EW control, operating the EW at full speed when it is cool outside reduces its capacity to do free cooling with the OA. In this more advanced control approach, the EW is placed in the off mode when the OA enthalpy is below the return air enthalpy until the OAT drops below the desired SAT setpoint. Therefore, it is able to do more free cooling with the OA than would be possible

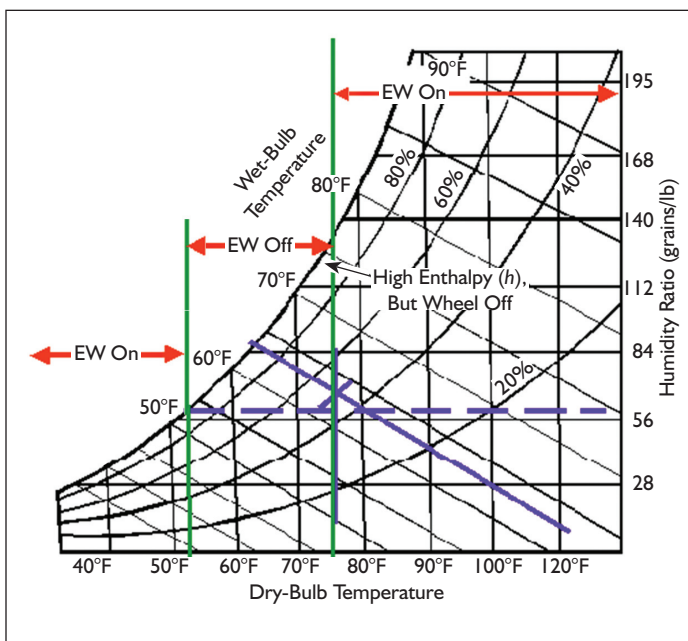


Figure 1: Incorrect enthalpy wheel control.

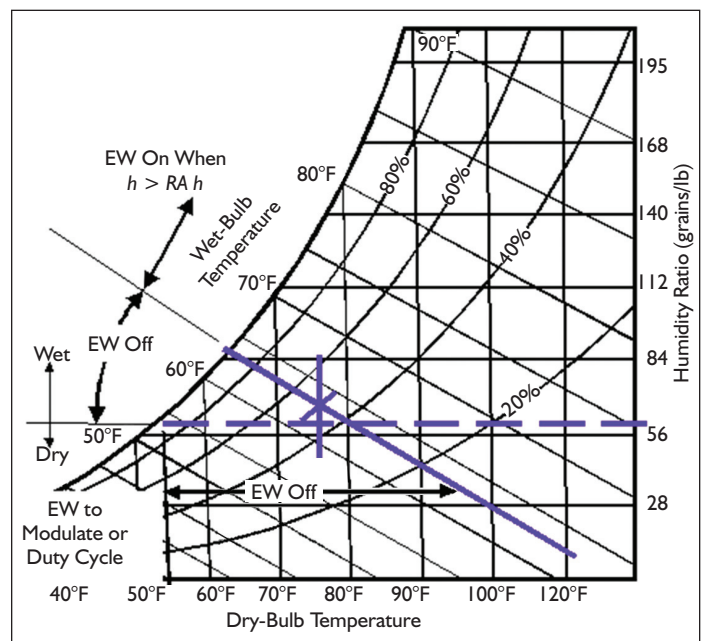


Figure 2: Recommended enthalpy wheel control.

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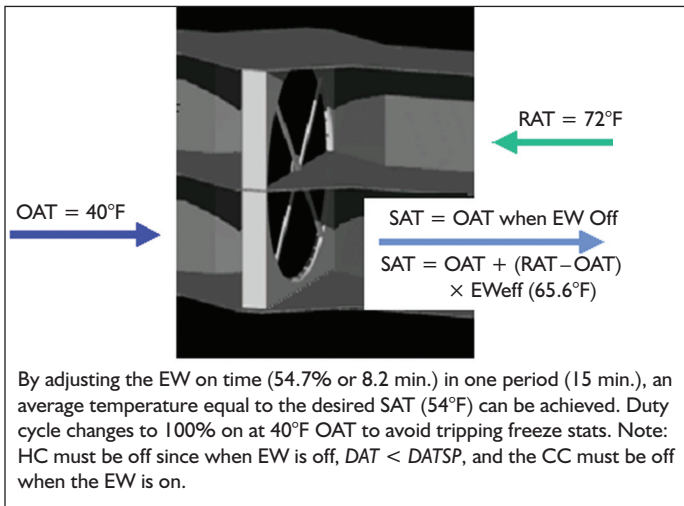


Figure 3: Enthalpy wheel duty cycling.

with a system operating the EW at full speed during all occupied hours. For OATs below the SAT setpoint, with the EW in the on mode, much if not all of the free cooling is lost.

The best control strategies for the EW are illustrated in *Figure 2*. This control minimizes the energy demand/use of the system while providing acceptable IAQ. First, if duty cycling (binary on-off control of the EW intended to provide an average SAT equal to the desired SAT setpoint) is selected to minimize first cost (i.e., EW variable frequency drive not required), some new control details must be accommodated.

Duty cycling can be characterized as illustrated in *Figure 3*. The duty cycle concept involves adjusting the EW percent on time within a cycle period to achieve the desired SAT. The on time is a function of the return air temperature (RAT), the OA DBT, the desired SAT, and the EW sensible effectiveness. To limit the number of times the EW is energized per hour, and hence the wear and tear on the drive, the period is often set at 15 minutes. As a result, the on and off times are frequently long enough for the EW SAT to reach nearly its steady state on or off value, which always will be above and below the desired SAT. Consequently, control of the heating and cooling coils when in the duty cycle mode become issues.

Since the SAT will drop below the desired SAT when the wheel is off in the cycle, but heating is not desired, the heating coil control valve must be closed during duty cycling. Similarly, when the EW is on in the cycle, the SAT will rise above the desired SAT, but cooling is not desired, so the cooling coil control valve must be closed during duty cycling.

Duty cycling is to be preferred to operation of the EW at full speed when the OA DBT is lower than the SAT setpoint. However, duty cycling can only operate down to a lower limit, which is a temperature just above that necessary to trip the low limit temperature sensor. To avoid tripping the entire system off and the IAQ problems that result from this, the EW is not permitted to duty cycle be-

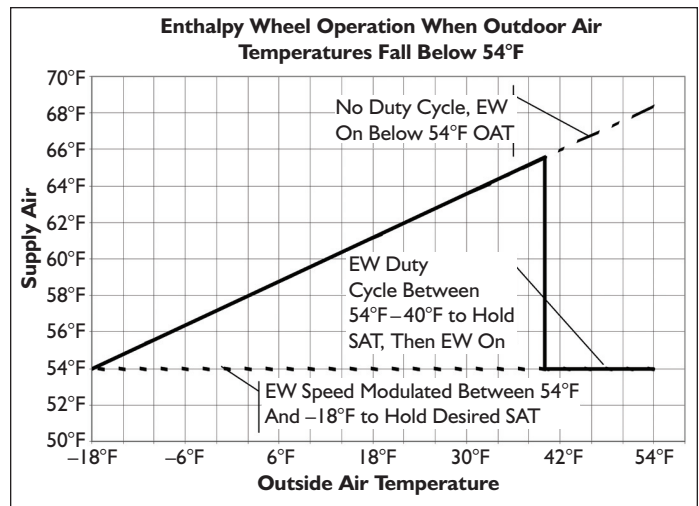


Figure 4: SAT for various winter EW controls.

low an OA DBT of 40°F (4°C). Consequently, duty cycling is not nearly as effective at reducing winter chiller operation via free cooling as the second control strategy, an EW with fully modulating VFD speed control.

As shown in *Figure 4*, when the EW is no longer permitted to duty cycle at 40°F (4°C), the SAT elevates from the 54°F (12°C) SAT setpoint to about 66°F (19°C), which is a loss of more than 1 ton (3.5 kW) of sensible cooling for each 1,000 cfm (472 L/s) of OA. A fully modulating EW with variable frequency drive (VFD) control could hold the desired SAT setpoint, in the example of *Figure 4*, down to an OA DBT of -18°F (-28°C).

When the EW speed is modulated using a VFD, the desired SAT can be achieved without concern for dropping the system out on low temperature. And the cooling/heating coils do not require any special control attention.

Another alternative to VFD is to use a bypass damper around the EW to modulate the leaving air temperature. Care should be exercised with that approach because of added equipment size, problems detecting true mixed air temperature, and introducing air stratification problems, which is the most frequent reason for coil freeze-up in mixing air systems.

Two other EW control problems observed in some projects are:

- Failure to provide a cleaning cycle when in the EW off mode; and
- Failure to provide EW frost protection.

The need for EW cleaning, caused by fine particles coming to rest and building up on the leading edges of the flute, when in the EW off mode, is easy to rectify by turning the EW on for about 1 minute (approximately 20 revolutions) per hour. As the wheel passes through reverse flow each revolution, the particles are easily dislodged and removed.

The other oversight is frost formation protection. Frost control at the EW when the OA is below freezing must be taken seriously. If frost forms, the pressure drop increases

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and the flow decreases. As the pressure differential increases, the wheel accelerates wear on the seals, which can lead to serious wheel damage. Many ways exist to prevent frosting problems, and the manufacturer's recommendations should be followed.

DOAS Coil Freeze Protection Pitfalls

Systems like the one in *Figure 5* present freeze protection questions. Unlike OA-return air mixed air systems such as variable air volume (VAV), stratification does not occur in DOAS systems as in *Figure 5*. In this particular application where no preheat exists, the cooling coil is located where it could be exposed to freezing temperatures. The intent of this section is to flag those circumstances, and suggest remediation.

It is clear that anything that would compromise the ability of the EW to recover heat from the exhaust airstream would result in its inability to elevate the OA temperature above freezing. Specifically, events that would compromise the flow of relief air past the EW include:

- Relief air filter loaded, reducing the airflow to the EW;
- Frost buildup in the EW. Once this process begins, frost will get progressively heavier, further restricting airflow;
- Failure of the EW drive, including belt, sheaves, motor, starters/VFD and controls;
- Problems with the exhaust air fan, including belt, sheaves, motor, bearings, starters and controls; and
- Problems with the exhaust air (EA) damper operation or control that would render it only partially open or closed.

The system requires continuous performance monitoring⁴ to prevent freeze damage. Since it is never desirable to terminate the flow of OA to buildings when occupied, it is best to have a flow-measuring device in the entering airstream (*Figure 5*) to detect reduced flow well before the EW effectiveness has deteriorated to the point that the system must be shut down due to low temperatures.

A passive fail-safe low-temperature sensor needs to be placed downstream of the EW in the OA path at the position illustrated in *Figure 5*, where the air leaving the EW would be at the lowest temperature. To be passive and fail-safe, the sensor must be hardwired into the fan motor starters and the two-spring return damper actuator. In an effort to make freeze protection passive, engineers are recommended to resist the temptation of operating the low-temperature control logic through the direct digital control system.

Engineers have a host of additional freeze protection approaches, all of which may be warranted in these systems. They include:

- Using brine solutions in the coils;
- Using secondary circulating pumps, which are activated during low temperatures;

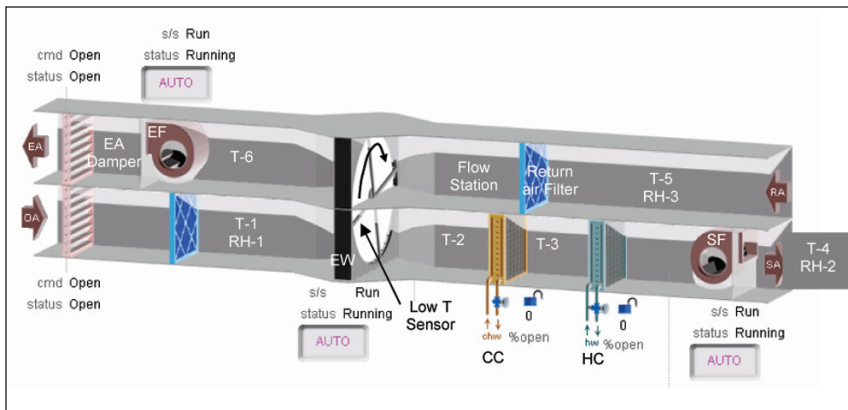


Figure 5: DOAS schematic from a Web-based control.

- Opening control valves to 100% during low-temperature events, and counting on the primary pumps to circulate water for freeze protection; and
- Draining the cooling coils in the winter.

Engineering judgment, cost, and liability dictate how far to take the freeze protection provision. In this author's experience, no DOAS coil freeze-ups have occurred when EW effectiveness has been maintained through monitoring the EA flow, and corrective action taken when reduced EA flow occurs before the low-temperature sensor kicks into action. On the other hand, coil freeze-ups are far too common in mixing air systems, which are troubled by stratification.

Conclusions

The importance of proper EW control has been discussed, with an emphasis on using enthalpy as a control variable to discern operating mode when it is humid outside. Also emphasized is the importance of using either a duty cycle, or preferably a VFD, to modulate the EW capacity when the OA DBT falls below the desired SAT to maximize the free cooling that the system can do.

Proper EW control significantly impacts the first cost of the cooling plant and the energy used by that plant. Also important are the EW cleaning cycle and frost protection.

Freeze protection is required since some DOAS do not have adequate precautions already in this important area. The EW effectiveness must be maintained, or the system could easily face the risk of a freeze-up.

References:

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