AIRXCHANGE

FROST CONTROL STRATEGIES FOR AIRXCHANGE ENTHALPY WHEELS

Frost Control Requirements

All energy recovery ventilation systems require frost protection or defrost means in climates experiencing severe winter design conditions. Frost formation results in a reduction and eventual blockage of airflow through the heat exchanger. The temperature below which frost will begin to accumulate on heat exchanger surfaces is referred to as the frost threshold temperature. It is a function of outdoor temperature and indoor relative humidity. Figure 1 compares the frost threshold of a typical plate-type sensible heat exchanger with that of a typical enthalpy wheel. Note that while frost forms at between 22 and 30 ^{O}F in a plate type exchanger, frost thresholds for enthalpy wheels are generally 20 to 30 degrees lower. This is due to the removal of water from the exhaust airstream by the enthalpy wheel, effectively lowering the dewpoint of the exhaust. The water removed is subsequently picked up (through desorption, reevaporation and/or sublimation) by the entering outdoor supply air.

Thus for areas with winter design temperatures between -5 ^{O}F and 22 ^{O}F (depending on the indoor RH), the enthalpy wheel component enjoys a significant advantage over sensible plate type units in that frost control is generally not required. Many regions where plate type units require frost control will not need frost protection for an enthalpy wheel application. Even in more northerly areas, applications such as schools and office buildings can be designed without frost control because most of the frosting hours are at night when the building is unoccupied. Bin data, such as that provided by ASHRAE or with the AIRX ERC performance modeling software, may be consulted to qualify daytime applications in cold climates for frost-free operation.

Table 1 lists frost threshold temperatures for Airxchange rotary energy recovery ventilation wheels over a range of indoor air temperatures and relative humidities. Note that the enthalpy wheel will tolerate limited hours of operation below the frost threshold without damage or significant reduction of airflow. Frost control is not required until entering air temperatures are below the threshold.

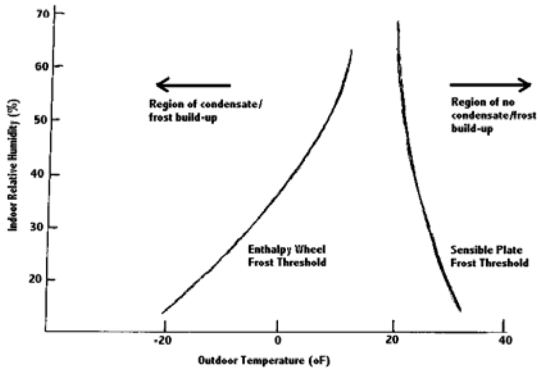

FIGURE 1:
Comparison of Frosting Thresholds of Enthalpy Wheels and Plate-type Heat Exchangers

Frost Threshold Temperature (°F)				
Indoor Air RH (%)	Indoor Air Dry Bulb Temperature			
	70° F	72° F	75° F	80° F
20	-14	-13	-11	-8
30	-3	-2	-1	3
40	5	7	9	11
50	12	13	15	18
60	18	19	21	26

TABLE 1:
Frost Threshold Guidelines for Airxchange Enthalpy Wheels

Frost Control and Energy Recovery Wheel Performance

While plate type heat exchangers can utilize a defrost strategy that allows ice to build up in the heat exchanger core and periodically defrost and drain the water away, this effect is not desirable in most commercial applications due to the reduction of ventilation rates during the freezing cycle. In addition, this approach requires condensate pans and drain lines, another reason why rotary wheels are generally specified for commercial space ventilation applications. In any case, allowing large quantities of frost and ice to form is not a viable option for the enthalpy wheel.

Enthalpy wheels can provide continuous frost-free operation at severe winter conditions if provided with controls to avoid the frosting threshold. Two methods are commonly employed: variable speed drive to reduce effectiveness of heat transfer and preheating of the outdoor air. Preheating is the generally preferred strategy from an energy savings and design load reduction standpoint. Figure 2 illustrates the psychrometric processes associated with both preheat and variable speed strategies for avoiding frost formation in enthalpy wheels.

The variable speed strategy depends on slowing the wheel down enough so that its reduced effectiveness leaves the exhaust air condition short of the saturation curve. Water is not accumulated and does not encounter below freezing temperatures. (See the top, shorter, process line in Figure 2 resulting in EA_V.) Contrast this with the preheat strategy in which there are two process lines: first, the incoming air is preheated (see the lower left hand side of the chart). Note that the new preheated outside air condition, OA_P, moves away from the saturation curve. Now the wheel sees OA_P as the outside air condition and can operate at full energy recovery effectiveness without encountering saturation, avoiding the frost threshold. The exhaust air condition with preheat, EA_P represents significant savings over EA_V. In this example, at -10^{O}F, approximately 2.5 Btu/lb. is used to preheat, while EA_P represents a differential of approximately 4.5 Btu/lb. over EA_V, a net savings of 2 Btu/lb. or 9000 Btu/h per 1000 cfm.

The cost of providing preheat should compare favorably with that of providing variable frequency drives and compatible wheel drive motors. In any climate where frost control is required for longer than a few hours due to severity of climate and/or humidification of the space, the preheat strategy will represent significant operating savings when compared to variable speed drive. Unless the number of hours below the frost control threshold is so small as to be insignificant, preheat is the preferred frost control strategy. In addition, preheat offers the greater reduction in heating plant design loads.

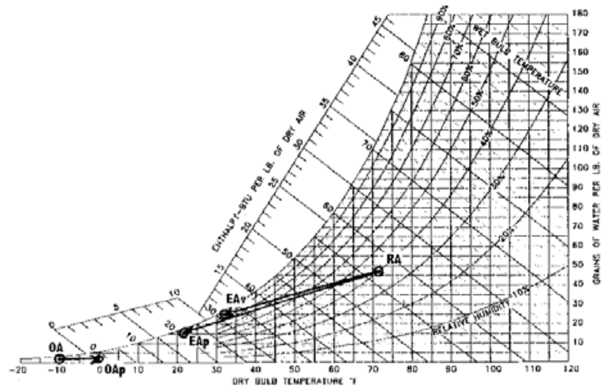

FIGURE 2:
Comparison of Preheat and Variable Speed Frost Control Strategies

Preheat Frost Control Methodology

As discussed above, preheat frost control is the recommended method of preventing frost formation and ensuring design outdoor air ventilation rates for most cold climate applications. For continuous operation below the frost threshold temperature, a preheater (electric preheating coil or hot water (glycol) coil) is installed in the outdoor air inlet airstream. The preheater should be automatically controlled to maintain a predetermined inlet air temperature. See Table 2. Note that the required preheat temperature at design is always below the frosting threshold for a given condition. This is due to the fact that preheating lowers the relative humidity of the outside air entering the wheel, effectively lowering the frosting threshold for any given set of indoor air conditions. Limiting the preheater capacity allows the maximum recovery of energy and the minimum preheater operating expense at design temperatures.

Outdoor Winter Design Temp.	Indoor Air (Return) Conditions					
	70^{O}F and 20%RH (Frost Threshold -14°F)		70^{O}F and 30%RH (Frost Threshold -3°F)		70^{O}F and 40%RH (Frost Threshold 5°F)	
	Preheat Temperature At Design	Required Capacity ΔT	Preheat Temperature At Design	Required Capacity ΔT	Preheat Temperature At Design	Required Capacity ΔT
5	-	-	-	-	-	-
0	-	-	-	-	2.5	2.5
-5	-	-	-4.3	0.7	0.8	5.8
-10	-	-	-6.3	3.7	-0.6	9.4
-15	-14.7	0.3	-7.9	7.1	-1.7	13.3
-20	-16.7	4.3	-9.1	10.9	-2.5	17.5
-25	-18.3	6.7	-10	15	-3.1	21.9
-30	-19.4	10.6	-10.7	19.3	-3.6	26.4
-35	-20.3	14.7	-11.3	23.7	-3.9	31.1
-40	-21	19	-11.7	28.3	-4.2	35.8

TABLE 2:
Preheat Frost Control Temperatures and Capacity (ΔT) Requirements at Selected Indoor and Outdoor Conditions (^{O}F)

To select the proper size preheater or preheat coil, determine the Btu's required to maintain the selected preheat frost control temperature at the lowest anticipated outdoor operating temperature. The Btu requirement is a function of the CFM of outdoor supply air and the temperature difference (DT) between the preheat temperature and the lowest anticipated operating temperature. The Btu requirement may be calculated as follows:

Required Btu/h = 1.08 x CFM x desired DT(^{O}F)
<u>or</u> Btu/h = 4.12 l/s x desired DT(^{O}C)

The preheater control consists of a temperature sensor to measure outdoor air temperature at the inlet to the wheel, and a temperature control unit to receive signals from the temperature sensor and maintain a constant intake air temperature through modulation of the electric heater energy or hot water (glycol mix) to the coil. The temperature sensor is located immediately before the wheel as required to adequately sense mixed air temperature and must be adequately shielded from radiant energy at the coil in order to assure accurate air temperature readings. Adhere to good practice guidelines in coil installation to assure proper airflow across the heating elements and to minimize temperature stratification in the supply air. Control setpoint should be in accordance with the frost thresholds listed in Table 1. Note that the control setpoint from Table 1 is always higher than the required preheat temperature from Table 2. This is due to the impact of the preheater on the entering air conditions, driving the outside air condition away from saturation and thus decreasing the amount of preheat required. On the other hand, we still need to begin the preheating process as the outside air conditions first reach the frosting threshold. Otherwise, we would see frosting at all conditions between the initial frost threshold and the required preheat temperature. The consequence is that we will typically use slightly more preheat energy than is required at initial frosting conditions. Another effect is that once the preheater capacity is fully utilized, the temperature will begin to slide down with the decreasing outdoor air temperature, still remaining above the required preheat temperature (which is also being lowered by the action of the preheater on the outdoor air as described above).

Variable Speed Frost Control Methodology

Variable speed control uses the degradation of effectiveness due to slowing the wheel rotation to prevent the deposition of excessive water, frost or ice on the wheel and ensure that any deposited water is able to be removed by the incoming air. Most wheels can be provided with this capability, however, as discussed above, this strategy is best applied only when the hours when frost control is required are limited. The suggested control strategy requires two sensors: the first looks at the dry bulb temperature of the outside air to determine if frost control is required. The control sequence would engage the variable speed system whenever outdoor temperature falls below a setpoint determined in accordance with Table 1.

The second sensor looks at the leaving exhaust air temperature and controls the wheel rpm to achieve a set minimum exhaust air temperature according to Table 3 below. As the wheel slows, losing effectiveness, less energy is recovered from the exhaust air allowing it to exit at a warmer temperature. The values in Table 3 have been derived from the accepted empirical model to allow entering supply air to remove all water deposited on the wheel by the exhaust.

The table illustrates the wide variation in requirements due to changes in outdoor temperature as well as the impact of indoor relative humidity. Changes in indoor temperature will also have an effect on the required leaving air condition and effectiveness. Changes in outdoor RH (assumed here to be 85% at design) have little impact on the results. Simple control algorithms are bound to waste significant energy. A more sophisticated control strategy might integrate the outdoor temperature information, continuously adjusting the required leaving air exhaust temperature according to need. Information on indoor temperature and relative humidity could also be integrated into the control. In any case, the use of variable speed control requires careful selection of both sensor and control components, compatible with motor operation. And in most applications, the use of the variable speed strategy significantly reduces the heating equipment savings at design. Consult Airxchange engineering if you wish to pursue this option.

70 ^{O}F and 20%RH Indoors			**70 ^{O}F and 30%RH Indoors**			**70 ^{O}F and 40%RH Indoors**		
Design Temp. ^{O}F	Effective-ness %	Exhaust Air Temp. ^{O}F	Design Temp. ^{O}F	Effective-ness %	Exhaust Air Temp. ^{O}F	Design Temp. ^{O}F	Effective-ness %	Exhaust Air Temp. ^{O}F
-13	0.80	4	-3	0.80	12	4	0.80	17.3
-15	0.70	11	-4.5	0.70	18	3	0.70	23.1
-19	0.60	17	-8	0.60	24	1	0.60	28.6
-26	0.50	22	-13	0.50	28.5	-3	0.50	33.5
-31	0.45	25	-17	0.45	31	-5	0.45	36.2
-40	0.40	26	-24	0.40	32.5	-10	0.40	38

TABLE 3:
Exhaust Air Leaving Temperatures and Wheel Effectiveness Requirements for the Variable Speed Frost Control Strategy

Alternative Strategies and Controls

On/Off Frost Control

For intermittent ventilation below the frost threshold temperature, a temperature control can be provided to shut down the energy recovery ventilation system when outdoor temperature drops to the control set point (as determined by the frost threshold temperature - Table 1). Operation may be automatically restored when outdoor air temperature rises above the thermostat set point. The thermostat should be located in the outdoor air intake hood or outdoor air intake duct as close as practical to the intake hood. On/Off Frost Control should only be used if the following considerations make intermittent ventilation acceptable:

A limited number of hours occur below the frost threshold temperature when natural ventilation rate is highest because of maximum indoor/outdoor temperature differential.

Temperatures below the winter design temperature usually occur during periods of darkness, typically between midnight and 7 A.M., with durations of one to six hours. Depending on the application, these low temperatures may only occur during unoccupied periods when ventilation is not required.

Exhaust Only Frost Control

For continuous mechanical exhaust below the frost threshold temperatures, a thermostat control can be provided to shut down the supply blower when outdoor temperatures reach the selected frost control setting. The thermostat should be located in the outdoor air intake hood or outdoor air intake duct as close as practical to the intake hood. To avoid depressurization of a building, automatic, or pressure operated fresh air dampers may be required as part of the building ventilation system.

Pressure Differential

Any of the strategies suggested above may be triggered through the use of a differential pressure sensor instead of the thermostat or temperature sensor. As frost builds in the wheel, pressure drop across the heat exchanger increases, indicating the need for frost protection. The advantage of pressure sensing is that it only responds to actual formation of frost in the wheel, automatically adjusting to variations in the frosting threshold due to changes in indoor humidity. This is the situation found in most buildings in cold climates where humidification is not present. Field experience shows that many non-humidified buildings will not actually experience frosting. A disadvantage of pressure sensing is that it must be set based on a change from the installed operating airflow and related pressure drop across the wheel for each specific application. Field experience has shown that a control point value of 50% increase in measured DP above that of the normal flow rate is adequate to protect the equipment and minimize reductions in airflow. The use of pressure differential is of particular interest when employing an on/off or exhaust only strategy in a marginal climate.

Summary

Frost control is required in cold climates to protect energy recovery ventilation components and assure continuous supply of outdoor air. Frost control strategies for enthalpy wheels should be designed to take advantage of their inherent low frosting thresholds and to minimize energy use while maximizing design load reductions. Preheat frost control is a universally applicable strategy which meets all design requirements. Variable speed control can be used to advantage in a limited number of applications. Several alternatives are available to address specific applications in marginal climates.

Pre-heat Frost Control Procedure – The Short Course

Refer to Figure 3. Plot indoor and outdoor design conditions on the psychrometric chart. (Example shown is for 70 ^{O}F and 30% RH and –10 ^{O}F.) Draw a line from the indoor (return air) condition tangent to the saturation line to the edge of the chart. The dry bulb temperature where this line crosses the 80%RH line (below the tangent point) is the frost threshold and the control setpoint. Draw the process line for pre-heat – a line of constant absolute humidity beginning at the outside air condition. Where this line crosses the first is the required pre-heat temperature at design. The delta between this point and outdoor design is the required pre-heat capacity.

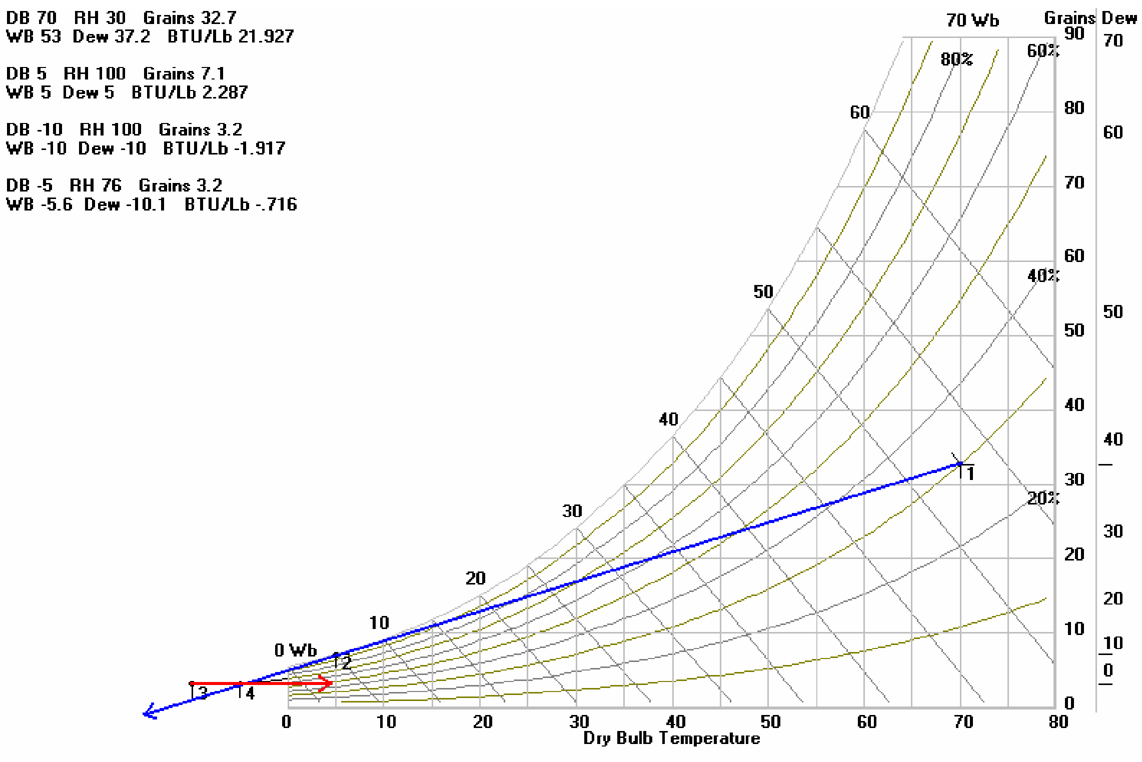

FIGURE 3:
Summary of Pre-heat Frost Control Procedure