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Frost Control for Enthalpy Wheels

IN THIS ISSUE

- Overview: Exhaust Energy Air Sources
- Frost Control Methods
- Annual Energy Savings
- GOLD RX and Frost Control

INTRODUCTION

The benefits of exhaust air energy recovery are well discussed as ventilation air is a significant part of the HVAC energy budget. *ASHRAE Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings* has continued to increase the requirements for exhaust air energy recovery during its past few issues (2007, 2010, 2013). The National Energy Code of Canada (NECC) also has requirements for exhaust air energy recovery.

For colder weather climates (4A, 5A, 6A, 7, 8) energy recovery for Dedicated Outdoor Air Systems (DOAS) is a requirement as per ASHRAE Std 90.1-2013 and the NECC 2015. Optimizing energy recovery for enthalpy wheels in cold weather climates requires managing frost control. This article will discuss the common methods of frost control and their impact on system performance.

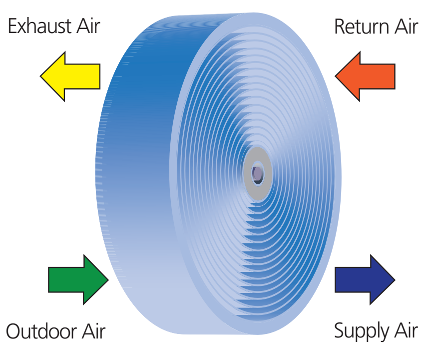

Figure 1 – Energy Recovery Device

EXHAUST AIR ENERGY SOURCE

In heating recovery, the exhaust air stream represents a heat source that has already been paid for. The air stream is warmer and more humid than the outdoor air during heating season. The goal of the energy recovery system is to extract as much ***enthalpy*** as possible. By enthalpy it is meant both sensible and latent heat. ASHRAE Std 90.1 requires that 50% of

> ***Cold Climate Example***
> *To help explain the concepts discussed in this article, the following system will be used based on Montreal, QC which has a winter design condition of -9.8 °F, 99.6% RH (-23.2 °C, 99.6% RH). The energy recovery device is a Swegon 3 angstrom AHRI 1060 certified enthalpy wheel sized for 5000 cfm (2360 L/s) supply and exhaust. The sensible efficiency is 80.3 %, latent efficiency is 82.9% for a total efficiency of 80.6%.*

the enthalpy is required to heat the outdoor air come from the exhaust air. This can be quite different than a 50% effective enthalpy wheel! The NECC is focused on sensible energy recovery. (See Cold Climate example).

What limits energy recovery is when the wheel starts to frost on the exhaust air side. As sensible energy is extracted from the exhaust air stream, the drybulb temperature drops and at some point the exhaust air drybulb temperature reaches saturation. If this happens below freezing (32 °F, 0 °C) then frost will form on the energy recovery device. As frost builds up the wheel performance will degrade (see Figure 2). Too much frost will block airflow and possibly damage the energy recovery device. Frosting represents the practical limitation of exhaust air energy recovery.

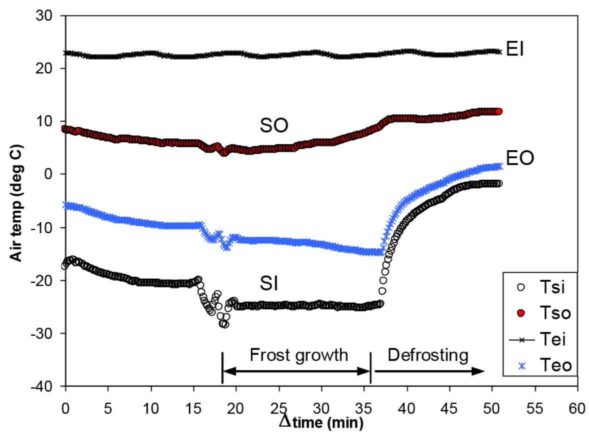

Figure 2 – Frost Formation on Energy Recovery Wheel [1]

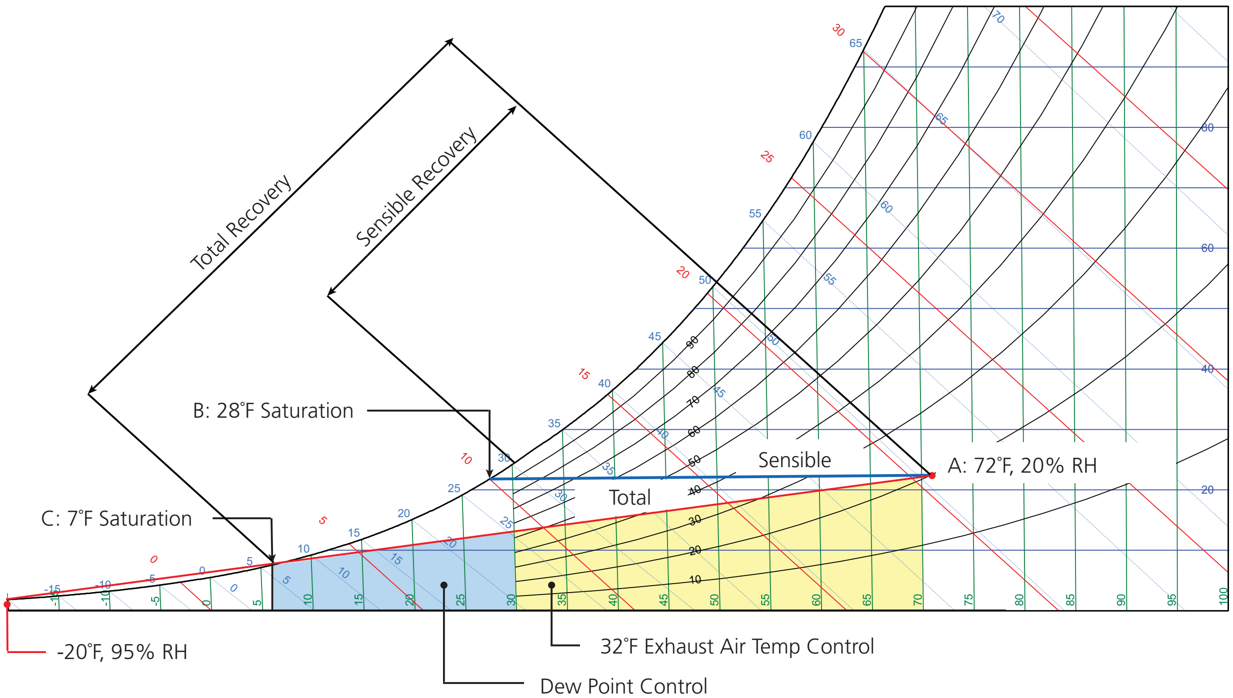

Figure 3 – Exhaust Air Frost Conditions

Referring to Figure 3 and using return air conditions of 72 °F db and 20% RH (22 °C and 20% RH) [Point A], saturation (dew-point temperature) is 28.7 °F (-1.8 °C) [Point B]. This is the minimum exhaust air temperature for a sensible heat recovery to avoid frosting.

Enthalpy wheels have a significant advantage over sensible devices. As the sensible energy is extracted from the exhaust air so is the latent energy (moisture) which lowers the saturation point. It has the effect of sloping the energy recovery process on the psychometric chart (see figure 3). Using the same return air conditions as before, saturation is now 7°F (-13.9 °C) [Point C]. The potential energy recovery is 64% greater for enthalpy-based devices over sensible-based devices.

OA DB	OA RH	RA DB	RA RH	Saturation
°F (°C)	%	°F (°C)	%	°F (°C)
-20 (-28.9)	95	72 (22)	20	7 (-13.9)
-20 (-28.9)	95	72 (22)	25	16 (-8.9)
-20 (-28.9)	95	72 (22)	30	22 (-5.5)
-20 (-28.9)	95	72 (22)	35	28 (-2.2)

Table 1 – Saturation Conditions

Table 1 shows the sensitivity of the saturation point to return air relative humidity at worst case conditions at -22 °F (-30 °C) for Montreal. The saturation point is also very sensitive to outdoor relative humidity. Small changes in either of these values will greatly impact when frosting will occur.

Assuming a return air condition of 72 °F and 20% RH (22 °C and 20% RH) for the Montreal example, frost will start to form when the outdoor air is around -16 °F and 95% RH (-26.7 °C and 95% RH).

FROST CONTROL METHODS

There are three common ways to control frosting when using enthalpy (or sensible) wheels. Each will be discussed in detail.

ROTOR SPEED FROST CONTROL

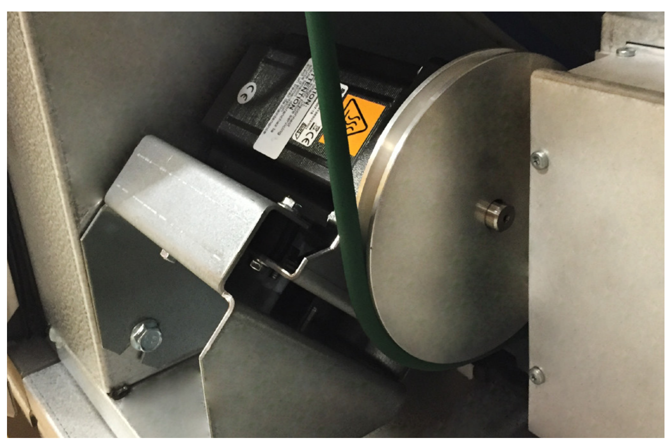

Figure 4 – Swegon GOLD Stepper Motor

[1] Mahmood, Gazi I., Simonson, Carey J., *Frosting Conditions for an Energy Recovery Wheel in Laboratory Simulated Extreme Cold Weather.* ASHRAE Transactions CC28

Varying the speed of the wheel is the most common method of frost control. Some form of speed controller (e.g. a VFD) is used to change the wheel motor speed, consequently reducing the energy transfer. This approach is cost effective and does not impact the size of the energy recovery unit.

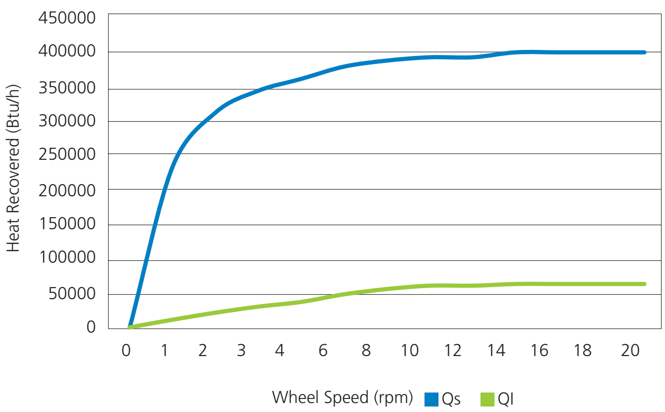

Figure 5 – Energy Transfers v.s. Wheel Speed

Figure 5 shows energy transfer vs. wheel speed for the Montreal example at -20 °F (-28.9 °C) outdoor air condition. The wheel will frost when the outdoor air temperature reaches -16 °F (-26.7 °C) then the wheel must slow down to avoid frosting.

Note there is no significant sensible energy reduction until the wheel is slowed to a few rpm. *If the motor speed controller cannot operate down to at least 1 rpm, there will be no real transfer control and frosting is a real possibility.* Once speed control is initiated the sensible and latent processes behave differently as can be seen in the different shape of their curves in Figure 5.

For the Montreal example to provide frost control below -16 °F (-26.7 °C) ambient, the wheel must slow down below 2 rpm. This will reduce the sensible heat transfer by 22%. At these low wheel speeds, the latent energy transfer is reduced by 66% showing how different the two heat transfer processes behave as the wheel speed is reduced. The loss in latent transfer negatively impacts the overall energy recovery opportunity when wheel speed frost control is used.

A common method for field installed controls is to supply a drybulb temperature sensor in the exhaust air stream and maintain an exhaust air temperature above 32 °F (0 °C) (See yellow area in Figure 3). This will easily avoid a frosting issue considering the design frost condition for the Montreal example is 7 °F (-13.9 °C). In fact, this is too conservative as it will sacrifice more than 15% of the annual energy savings by prematurely slowing the wheel down.

A different approach is to measure the pressure drop across the wheel. If frost does form on the wheel then the rotor pressure drop will increase and a control algorithm slows wheel to allow defrost (See blue area in Figure 3). In the Montreal example, the frost control algorithm would only be required for 9 hours/year. For most applications frosting may not happen at all. Generally, wheel speed frost control provides the most reliable, cost effective solution while optimizing energy recovery.

PREHEAT FROST CONTROL

Figure 6 shows an energy recovery wheel with preheat applied to the outdoor air. The goal is to preheat the air just enough to avoid frosting. Including a preheat coil with cabinet and controls adds cost to the energy recovery unit and increases the unit size.

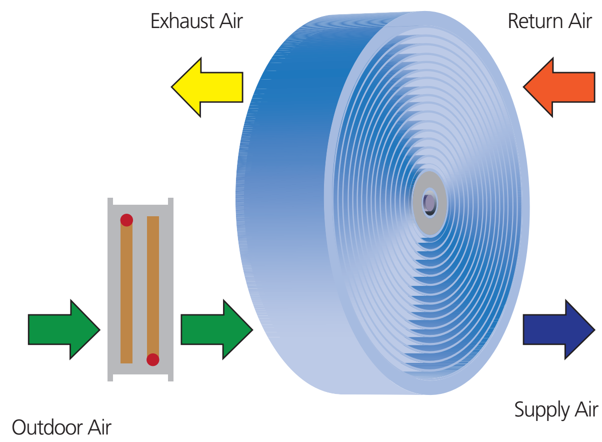

Figure 6 – Enthalpy Wheel with Preheat

Figure 7 shows the impact of preheating the outdoor air. Artificially raising the outdoor air temperature with preheat lowers the energy gradient across the wheel and hence the sensible energy transferred as reflected with the blue line. The latent capacity is not affected since the humidity ratio of the outdoor air remains unchanged.

To avoid frosting in the Montreal example, the outdoor air needs to be preheated to -16 °F (-26.7 °C) whenever the ambient temperature is lower.

Analytically, preheat frost control offers the best energy performance while avoiding frosting. See *Establishing Preheat Supply Air Temperature* to estimate the control point.

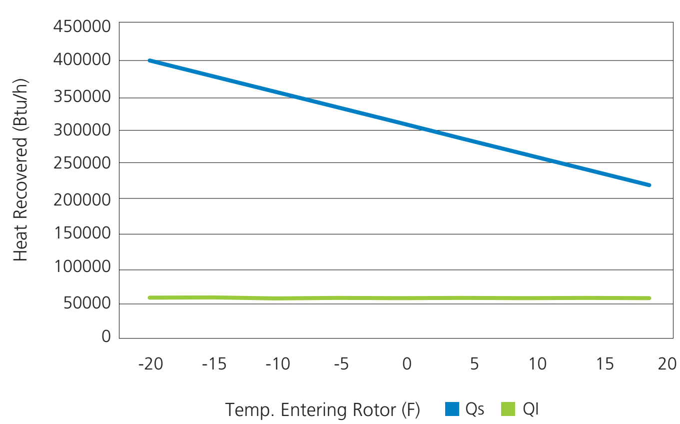

Figure 7 – Heat Recovered vs. Temperature Entering Rotor

In very cold climates, hoar frosting will require preheat as the only solution for frost control. In this kind of environment, hoar frosting will form on filters, energy recovery wheels etc. ultimately blocking off the airflow. Preheat is used to warm the air before it passes through the winter filter rack and the energy recovery device.

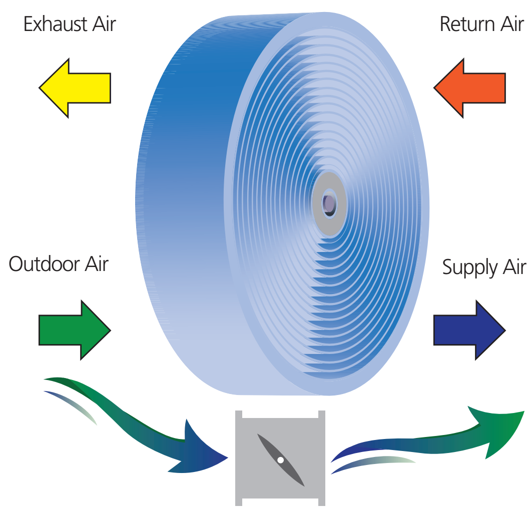

Figure 8 – Energy Recovery Wheel with Bypass

BYPASS FROST CONTROL

Figure 8 shows an energy recovery wheel with bypass dampers. The dampers allow some of the outdoor air to bypass the wheel reducing the air volume passing through the wheel. Reducing the airflow through the wheel will reduce the amount of energy extracted from the exhaust air stream so it can be used to avoid frosting. In most cases, the wheel size sets the width and height of the cabinet. Adding bypass dampers can increase the cabinet size by 20%, increasing both cost and space requirements.

Figure 9 shows the heat transferred vs. the amount of outdoor air bypassed around the wheel. For the Montreal example, 500 cfm (236 L/s) (about 10%) of outdoor air must be bypassed to avoid frosting. Bypass frost control uses a similar control method as wheel speed control with either exhaust air temperature control or wheel pressure drop control.

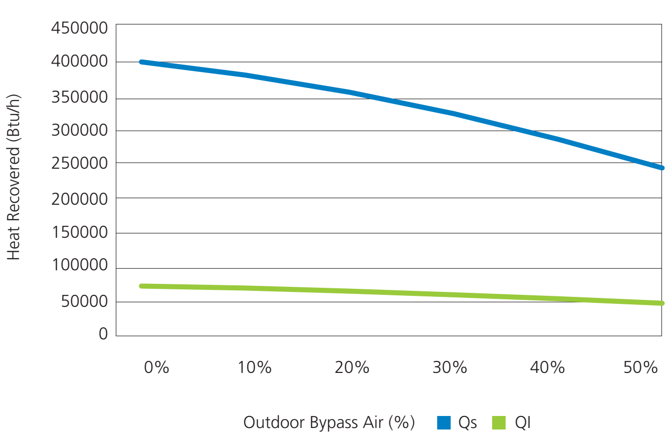

Figure 9 – Heat Recovered vs. % outdoor air Bypass

ANNUAL ENERGY SAVINGS

Figure 10 shows the energy savings for the Montreal Example for Preheat, Bypass and Wheel Speed Frost Control. There is no difference in energy savings between the three approaches until there is a potential for frost condition. In this example a frost condition only exists for 9 of the 5658 hours heat energy recovery occurs.

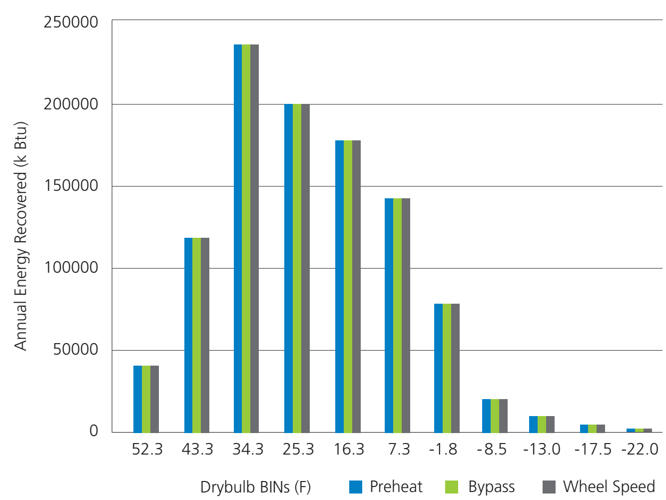

Figure 10 – Annual energy Savings of Three Frost Control Methods

SUMMARY

- Exhaust air energy recovery is one the best ways to improve a building energy footprint and is a requirement in both ASHRAE Std 90.1 and the NECC.
- Enthalpy wheels can extract 64% more energy than sensible devices due to latent transfer and the reduced saturation point but only if there a control algorithm to take advantage of this capability.
- The amount of exhaust air energy that can be recovered in cold weather climates is limited by the point where frosting will occur on the energy recovery device.
- From an analytical point of view, all three common frost control approaches (Wheel speed, Preheat and Bypass) provide adequate frost protection. Wheel speed control has a slightly lower energy transfer rate during frosting conditions due to the drop in latent transfer at low wheel speeds.
- Many cold weather locations only reach frost condition a few hours a year. For these locations wheel speed control is the most cost effective and space conservative way but will only be effective if the speed control can operate below 2 rpm. Using wheel pressure drop to recognize a frost situation and slow the wheel is reliable and produces the best energy transfer results.
- For very cold climates, preheat is the only option to avoid Hoar frosting.
- Differing supply and return airflow rates will impact the energy that can be recovered and the settings used to operate the system.

GOLD RX UNITS AND FROST CONTROL

The Swegon GOLD RX unit includes a 3 angstrom AHRI 1060 certified enthalpy wheel that is typically above 80% total efficiency. The wheel motor is a stepper type than can operate down to 0.5 rpm providing effective wheel speed frost control. The integral unit mounted controls include both exhaust air dry bulb temperature control and wheel pressure drop control that will allow the wheel to transfer maximum energy and only slow down if a frosting condition occurs. Once the frost has been removed, the wheel will return to full capacity.

Swegon units can also include steam, hot water or electric preheat coils as well as winter and summer filter racks for very cold climates where Hoar frosting can occur.

Establishing Preheat Supply Air Temperature

Knowing what supply air temperature to use when applying preheat is important in sizing the preheat coil and setting up the control algorithm. The following method can be used;

- *Establish worst case winter drybulb temperature from ASHRAE climate data or local experience.*
- *Assume 95% outdoor relative humidity (assume it is snowing). This is a conservative assumption in most cases.*
- *Establish a return air drybulb temperature. Typically it is around 72 °F (22 °C).*
- *Establish a return air relative humidity. If active humidification is being used, then use the design condition. If no humidification is being added, use 20% RH. This is a conservative estimate.*
- *Locate the outdoor air and return air points on a Psychometric chart and draw a line between the two points. Where the line crosses the saturation line is the saturation point.*
- *Add a safety factor to the saturation point to size the preheat coil. Consider a 10 °F (6 °C) safety factor.*
- *To size the reheat coil in mission critical applications use the supply air temperature from the preheat coil as the inlet air temperature to the reheat coil. The assumption is the energy recovery device has stopped working.*
- *To size the reheat coil in a non-mission critical application, use the discharge air temperature from the energy recovery device as the inlet air temperature to the reheat coil. Double check the design by adding the preheat to the reheat capacity and make sure the supply air temperature is at least above freezing. In this scenario, if the energy recovery devices stops working, supply air temperature will not causing a freezing situation in the building.*

EXAMPLE

Location; Montreal

Application; Office (Non-mission Critical)

Winter worst case Drybulb Temperature; -20°F (-28.9 °C)

Winter worst case relative humidity; 95%

Return air drybulb temperature; 72 °F (22 °C)

Return air relative humidity; 20%

Outdoor airflow rate; 5000 cfm (2360 L/s)

Return airflow rate; 5000 cfm (2360 L/s)

SOLUTION

PREHEAT COIL DESIGN

Airflow; 5000 cfm (2360 L/s)

EAT; -20 °F (-28.9 °C) and 1.4 gr/lb (0.0031 kgv/kga)

LAT; 7 (saturation point) + 10 (safety factor) = 17 °F (-8.3 °C) and 1.4 gr/lb (0.0031 kgv/kga)

ENERGY RECOVERY DEVICE

Outdoor Air Condition; 17 °F, 1.4 gr/lb (-8.3 °C, 0.031 kgv/kga)

Return Air Condition; 72 °F, 20% RH (22 °C, 20% RH)

Supply Air Condition; 61.2 °F, 19.5 gr/lb (16.2 °C, 0.043 kgv/kga)

Exhaust Air Condition; 27.8 °F, 24.1 %RH (-2.3 °C, 24.1% RH)

REHEAT COIL DESIGN

Airflow; 5000 cfm (2360 L/s)

EAT; 61.2°F and 19.5 gr/lb (16.2 °C, 0.043 kgv/kga)

LAT; 72 °F, 19.5 gr/lb (22 °C, 0.043 kgv/kga)