# Energy Calculations, Effectiveness and Frost Protection for Heat Recovery Exchangers in the ER-3 Controls Package

(Cross-Flow Plate Exchangers and Heat Pipes)

(*Nelson Howard – 11/2021*)

Frost protection is an important aspect of a heat recovery system. While there are many strategies and methods in use, all I have discovered involve using energy to pre-heat the incoming air from outdoors to prevent frosting, or modulating face and bypass dampers to reduce load on the heat recovery exchanger.

Pre-heating the incoming air works well on paper, but the end result is questionable as energy is needed to pre-heat the incoming air. Although it would work, it seems counter intuitive to pay to pre-heat the air you are trying to heat for free.

Modulating face and bypass dampers to reduce load works well, but there seems to be a lack of understanding in the industry as to when and how to control the dampers. Some will say to begin modulating them at an outdoor air temperature of 36°F, others will say to modulate them based on an exhaust air temperature of 36°F and yet others will say to modulate them based on static pressure drop on the basis that as the exchanger begins to frost the static pressure will increase.

While all of these will work, they forget about the effect this has on the effectiveness of the heat recovery exchanger. Modulating the face and bypass dampers too soon, or too much, will reduce the effectiveness of the heat recovery exchanger while waiting for frost to cause a static pressure drop will reduce the effectiveness while also reducing airflow and increasing load on the fan (thus increasing energy use). The best frost protection is predictive enough to prevent frost while maintaining the best possible effectiveness of the heat recovery exchanger.

Companies that provide heat recovery exchangers will often provide a data sheet with their equipment. This data sheet will have various temperature limits for condensate and frost prevention. These limits are only good at the temperatures listed on the data sheet, and often assume the outside and return air densities are the same. If frost protection strategies are developed around these data sheets they will often fail in the field as outside air density and return air density are seldom the same (10°F outside air at 85% RH has a different density than 68°F return air at 40% RH). To get accurate results for frost protection strategies these differences must be included in the calculations.

The logic in the **ER-3 Energy Recovery Controls Package** uses enthalpic calculations to optimize the effectiveness of the heat recovery exchanger, while preventing the buildup of frost/ice which would reduce the effectiveness or diminish the use of the exchanger. Using enthalpic calculations, the exhaust condensate temperature, supply air humidity, exchanger effectiveness, total transferred BTU's and outside air frost temperature are derived to optimize effectiveness while preventing frost and ice buildup.

**Exhaust Condensate Temperature** – (t-cond) [t4c]

The Return Air Dew Point [t3d] is the exhaust condensate temperature. When the return air is cooled through the exchanger to dew point, condensation will form on the exchanger fins.

**Supply Air Humidity** – [t2h]

Outside Air Dew Point [t1d] is referenced. As moisture content will not change as air passes through the heat recovery exchanger, supply air dew point will equal outside air dew point. As dew point is a calculation of temperature and relative humidity, supply air temperature and supply air dew point are used to calculate supply air humidity. This value is then used in the enthalpy calculations for effectiveness and frost protection.

**Heat Recovery Exchanger Effectiveness** – [E]

The performance of a heat recovery exchanger is referred to as effectiveness. Effectiveness is derived by using the formula **((t2 – t1) / (t3 – t1) * 100)** to get the percentage value.

**Total BTUh Transferred –** [T-BTUh]

The First Law of Thermodynamics (Law of Conservation of Energy) states that "*Energy is Neither Created nor Destroyed".* As heat recovery exchangers simply transfer energy from one airstream to another, they follow this law.

Enthalpy [H] in btu/lb. is the energy being transferred. The BTU's added to the supply airstream will equal the BTU's removed from the exhaust airstream. It is important to take the air density of each air stream as well as the CFM of each air stream in to account when doing this as different air densities and CFM's will have a direct effect on how the transferred BTU's are applied towards the enthalpy calculations.

At current operating conditions [E] subtract the exhaust air enthalpy [H4] from the return air enthalpy [H3] to get the total enthalpy being transferred [Htotal]. Use the current temperature, relative humidity and atmospheric pressure to calculate the Exhaust Air Density [D2]. Multiply the exhaust air density by the exhaust CFM [CFM2] to get the pounds of exhaust air being moved [LBS2], then multiply this by the enthalpy being transferred to get the total BTU's being transferred per minute [BTUm]. Multiply this by 60 to get the BTU's being transferred per hour [BTUh].

**H3 – H4 = Htotal**

**D2 * CFM2 = LBS2**

**LBS2 * Htotal = BTUm**

**BTUm * 60 = BTUh**

This will equal the BTU's added to the supply air stream. Use the density of the supply air [D1] and the CFM of the supply air [CFM1] to calculate the pounds of supply air [LBS1]. Divide the BTU per minute [BTUm] by the pounds of supply air to get the enthalpy added to the supply air [H2a].

**D1 * CFM1 = LBS1**

**BTUm / LBS1 = H2a**

**<u>Outside Air Frost Temperature</u>** – (t-frost) [t1f]

T-frost is the outside air temperature at which the exhaust air dew point is driven below freezing at current operating effectiveness. Calculating t-frost is done with the following.

Since we know the exhaust air stream will freeze at 32°F@100%RH, use this enthalpy as a reference (12.0309 btu/lb.).

Subtract the above reference from the return air enthalpy [H3] to get the amount of enthalpy that can be removed [H3r] from the return air stream before the exhaust air stream reaches the freezing point.

**H3 – 12.0309 = H3r**

Multiply this by the pounds of return air [LBS2] to get the total number of BTU's which can be removed from the return air [BTUr].

**LBS2 * H3r = BTUr**

This is the total number of BTU's that can be added to the outside air stream. By working the calculations into the outside air conditions, the outside air frost temperature (t-frost) can now be calculated.

The outside air frost temperature (t-frost) is now used as an early warning signal, in conjunction with return air dew point and exhaust temperature for the purpose of true enthalpic frost protection, keeping the heat recovery exchanger operating at optimum effectiveness.

This method works equally well on both, cross-flow plate and heat pipe exchangers as well as systems with varying or different supply and exhaust airflow volumes.

**<u>Continuous calculations include:</u>**

Supply Air Humidity (%RH)

Exhaust Condensate Temperature (t-cond)

Outside Air Frost Temperature (t-frost)

Current Effectiveness (%)

Total BTU's Transferred (T-BTUh)

**<u>Symbols used:</u>**

[CFM1] – Supply CFM

[t4c] – Exhaust Air Condensate Temperature

[t2] – Supply Air Temperature

[T-BTUh] – Total BTU’s Being Transferred

[Htotal] – Total Enthalpy Transferred

[D1] – Supply Air Density

[D2] – Exhaust Air Density

[LBS1] – Supply Air Pounds

[BTUm] – BTU’s Per Minute

[H2a] – Supply Air Enthalpy Added

[E] – Effectiveness

[H3] – Return Air Enthalpy

[RH] – Relative Humidity

[CFM2] – Exhaust CFM

[t1] – Outside Air Temperature

[t3] – Return Air Temperature

[t1d] – Outside Air Dew Point

[t1f] – Outside Air Frost Temperature (t-frost)

[t2h] – Supply Air Humidity

[BTUr] – Total BTU’s Removed

[LBS2] – Exhaust Air Pounds

[BTUh] – BTU’s Per Hour

[H3r] – Return Air Enthalpy Removed

[H] – Enthalpy

[H4] – Exhaust Air Enthalpy