A Holistic Review of Energy Recovery Ventilator System Sanitation, Sustainability and Economics

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Abstract:

This work aims to review the sanitation, maintenance, and return on investment (ROI) considerations over the life of the product for operation of Energy Recovery Ventilators (ERV) in light to medium duty commercial and industrial applications in the United States. A review of system maintenance and infectious disease risk with ERV are discussed. Additionally, with recent advancements in Dedicated Outdoor Air System (DOAS) efficiency due to new compressor and controls technologies, the assumptions of ROI for ERV systems demands a review. Current codified guidance offers many exceptions to ERV use where ventilation rates would otherwise demand their inclusion. Suggestions for when the Engineering Community should consider alternatives are discussed.

Introduction:

The use of Energy Recovery Ventilators (ERV) for commercial and industrial building systems was first codified in ASHRAE 90.1-1999. Minor revisions have been made to the standard over the past two decades although significant technology and controls advancements have been made over the same period.

As the use of ERV is codified, many in the engineering community assume they are to be included by default for many outdoor air applications, however misapplication is common. Lack of awareness in the engineering community as to proper application of ERV results in poor performance, dissatisfied users, health and safety risks, and the potential for lawsuits.

Many technologies for energy recovery exist, however the North American market has largely consolidated on the use of desiccant Total Energy Wheels, primarily due to the code requirement that total (sensible and latent) energy recovery efficiencies must meet or exceed 50%. As such, this work solely discusses the use of desiccant wheel technologies, although much of the data provided would apply to alternative air-to-air exchange devices.

Total Energy Wheels operate on the principle of utilizing exhaust and supply airstream enthalpy differentials via a desiccant membrane, typically in a rotating wheel design as in Figure 1. Energy wheels are widely available as isolated units, or factory incorporated additions, to the inlet of packaged Roof Top Unit (RTU) or Dedicated Outdoor Air System (DOAS) designs.

The principal of operation behind most Total Energy Wheels is that they rotate between the two airstreams, typically in the sub-200 RPM range, exchanging the sensible and latent differentials between the outgoing and incoming airstreams. To obtain reasonable efficiencies, a substantial portion of the design supply airstream must return to the unit via exhaust after cooling or heating the space, resulting in relatively complicated exhaust duct systems that run through multiple zones or floors.

Figure 1 – Total Energy Wheel

Sanitation and Bypass Concerns:

Inherent to their design, energy wheels have varying levels of air exchange between the outgoing exhaust air and incoming ventilation air. The cross contamination of exhaust and supply airstreams is referred to as the Exhaust Air Transfer Ratio (EATR). The EATR percentage is dependent on many factors, such as wheel design, construction quality and pressure differential between the opposing airstreams.

ASHRAE 62.1, the industry standard for definition of acceptable indoor ventilation rates, defines air contamination levels from class 1 to class 4 for varying degrees of contamination. Class 1 (clean air) is suitable for recirculation, whereas class 4 air (hazardous air) is not suitable for recirculation in any system. As it relates to energy recovery systems, ASHRAE 62.1-2010 defined criteria for utilization of a contaminated exhaust airstream with an ERV processing a lower class of uncontaminated supply air. A defined maximum of 10% EATR of the airstreams is outlined to utilize class 2 exhaust air with class 1 supply air, or 5% to utilize class 3 exhaust air with class 1 supply air.

As a method to verify EATR percentages, ASHRAE Standard 84 was developed, which specified the use of a Sulfur Hexafluoride tracer gas at various face velocity and pressure differential ranges. Unfortunately, AHRI released test standard 1060, the standard for *Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation Equipment*, which later allowed manufacturers to test EATR at their own chosen design condition, as opposed to multiple face velocities and pressure differentials. Many manufacturers of ERV claim EATR between 2-10%, however the test standard has numerous shortcomings, namely:

- The test in standard 1060 is performed at two static points, the rated unit airflow and 75% of this value. Laboratory testing and numerous published studies have shown that EATR rates vary greatly as face velocity and pressure differentials change (1).
- The test is performed only utilizing a tracer gas, not actual contaminant particles of varying sizes from sub-micron through micron ranges. It is therefore not an accurate representation of the particles of concern and may in fact provide a result that is an order of magnitude lower than actual (2).
- Both the ASHRAE 84 and AHRI 1060 standard reference a test measurement uncertainty ranges up to +/-7% for tracer gas and +/-10% for pressure differentials.

Notably, both class 1 and class 2 airstreams can carry airborne pathogens, viral disease, and other particulates in the range of 10 µm or smaller. Pathogens in the aerosol or nuclei form can be carried throughout a building, from a bathroom or similar contaminated zone, and transferred back into the incoming ventilation supply airstream. ASHRAE 62.1-2016, Section 5.16.3.2.5 prohibits the recirculation of class 2 air into class 1 airstreams, with the notable exception of ERV bypass leakage. Considering the questionable test methods for EATR, many ERV may not actually be in compliance with ASHRAE 62.1 as installed in the field.

As pathogen nuclei have been shown to survive on surfaces for periods in excess of 72 hours, even after evaporation of the droplet that carried it to the surface, it is logical that as a drier exhaust airstream is impacted by a highly latent supply airstream, particularly at high supply face velocities, rehydration and carryover of the nuclei into the supply airstream is likely (3). The desiccant membrane itself may be a gathering point for pathogens. Until this mechanism is further understood, use of ERV for sensitive applications should be reconsidered. ASHRAE Standard 62.1 ventilation rate guidance is suggested for schools, prisons, nursing homes, shelters, and other public facilities. This standard may insufficiently address this risk as it relates to ERV bypass leakage. ASHRAE Standard 170, Ventilation of Health-Care facilities, covers specific mandatory requirements for Health-Care facilities. Notably, even Standard 170 does not address the risks of bypass and energy wheel sanitation in discussion of ventilation rates for sensitive zones, and simply follows a slightly more stringent standard of 5% EATR. Recent updated guidance outlined in the ASHRAE Position Document on Infectious Aerosols, in the wake of the 2020 Coronavirus pandemic, recommends that ERV systems be disabled or bypassed completely.

In addition to EATR, inherent to their design, ERV bring the exhaust and supply intake and discharge louvers in proximity. Short circuiting between the exhaust discharge and supply inlet is increased dramatically as a result. A traditional approach with isolated exhaust fans would typically have a separation distance in excess of 10', whereas most ERV have little or no separation.

One often overlooked factor is the filtration of the exhaust and supply airstreams. When considering traditional mechanical filtration methods for sanitation and airstream cleanliness, one must remember that the filtration only works when the airflow is unidirectional. In the case of an energy wheel, the airflow is bidirectional, depositing the contaminants on the wheel, and then pulling them back off the wheel in the opposite direction as it rotates into the supply airstream. To avoid this conundrum, high quality exhaust air filtration is recommended before the contaminants can impact the wheel, as well as after the supply airstream has left the wheel and entered the HVAC unit.

Lastly, most manufacturers of ERV do not address odor in their design. Odor is introduced into the supply airstream via the bypass mechanism, but also the ERV wheel itself. The ERV membranes emit an odor when left idle or poorly maintained, often referred to as "dirty sock syndrome". ERV odor has been the basis of many lawsuits and application failures.

As ERV, compared to traditional ventilation design strategies, exist solely to reduce energy and *serve no other purpose*, the static pressure and fan energy implications of higher quality HEPA filtration must be factored into the economic equation.

Maintenance Considerations:

Energy wheel media under low RPM rotation are a relatively low stress mechanical device. As such, upon initial review of a unit, one might conclude maintenance expenses would be a relatively minor consideration in the economic equation for implementation of an ERV strategy. This would be a costly mistake, one that has significant financial implications for the building owner.

The reality is that there are numerous maintenance items which must be considered:

1. The sensitive desiccant media itself must be cleaned regularly for sanitation and efficiency purposes or replaced if contaminated due to a belt or other mechanical failure
2. The energy wheel has a motor, pulley and belt that requires maintenance
3. The exhaust airstream requires high quality filtration which requires more frequent changeout intervals than traditional ventilation air due to higher contaminant concentration
4. Due to higher static pressure resulting from the exhaust filtration and energy wheel itself, a larger horsepower exhaust fan (and often accompanying belt, shaft and bearings) must be maintained
5. For proper operation, an array of sensors and controls which are often subject to component failure, drift and inaccuracies must be monitored and maintained.

The reality is that an ERV is a complex machine. Accounting for the maintenance and the specialty skilled labor that can properly commission and maintain such a system must be a component of the economic equation.

Installation Complexities:

For proper operation of an ERV, the majority (ideally all) of the supply airstream must return to the unit as exhaust air. The ducting to return the exhaust airstream to the ERV is often a major building expense. Figure 2 depicts a common arrangement, highlighting the substantial exhaust duct requirements. Alternatives without the inclusion of an ERV may include barometric relief or simple powered roof ventilating exhaust fans (PRV), both extremely low-cost options. Recognizing that routing exhaust back to a unit may be cost prohibitive in many buildings, current code (ASHRAE 90.1-2017, IECC-2018, and IMC-2018) all outline that exceptions may be made if the summation of exhaust air within 20' of each other is less than 75% of the total air exhausted. This exception is often overlooked, misunderstood, and underutilized, straddling the consumer/building owner with an expensive and complex exhaust duct run and ERV that would otherwise be unnecessary.

Other installation costs are often overlooked in the economic evaluation of ERV. ERV are a sizable structural element in roof design, consuming valuable roof space and often weighing in excess of 50% of a matching Dedicated Outdoor Air Unit (DOAU). ERV require upsized exhaust fans due to high static pressure with their respective electrical requirements, breaker panel space, and controls wiring. ERV require additional shipping, craning, roof curb and flashing elements. All these factors are rarely considered in a return on investment calculation.

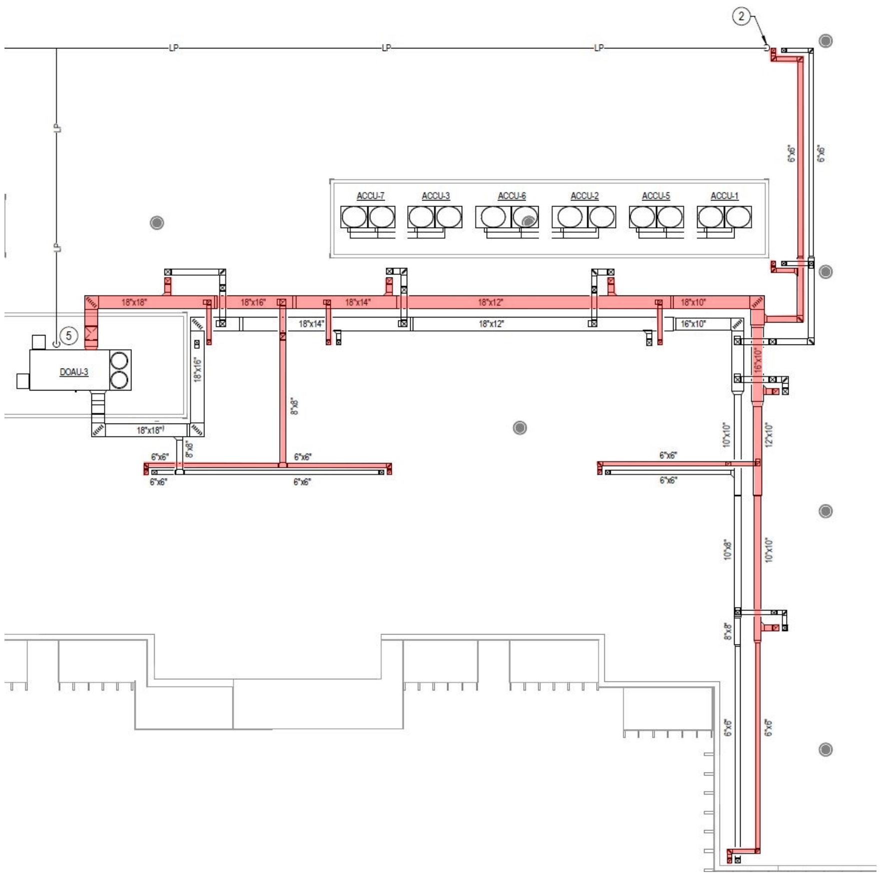

Figure 2- Typical exhaust duct run requirement for implementation of ERV

The Energy Efficiency Lie:

As DOAS unit efficiency increases, the amount of energy to be saved by an ERV proportionally decreases. With advancements in inverter scroll compressor technology, load matching EC motor condensing fans, electronic expansion valves, and modern control algorithms, DOAU efficiency can exceed IEER Ratings of 20. When ERV use was originally codified, an economic evaluation was performed to justify their inclusion in code. At that time, the minimum energy efficiency of units allowed by ASHRAE 90.1 was nearly half of the average energy efficiency of inverter scroll DOAS equipment readily available on the market today. Figure 3 depicts average unit efficiencies for major manufacturers in the year 2020 vs efficiencies of standard scroll compressor technologies of two decades ago. With 40% less energy consumed, the remaining energy to be recovered, and the proportional return on investment calculation, may be invalid.

As discussed previously, energy wheel efficiencies can drop substantially, below 25%, when there is an imbalance between the two airstreams (2). Proper building design includes positive pressurization to avoid infiltration at doors, windows and other envelope entry points. The Engineering community should therefore assume, in their default efficiency estimates for return on investment calculations for ERV use, an imbalance in the supply and exhaust airstreams. A portion

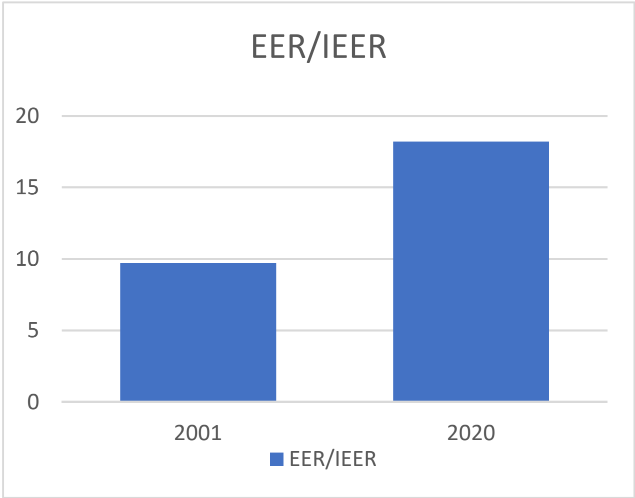

Figure 3 - Comparison of DOAS Energy Efficiencies

of the supply air must be reserved to maintain building pressurization. Unfortunately, AHRI Standard 1060 only tests the efficiency of a system in ideal arrangements, such as with an equal balance of supply and exhaust airstreams. It is suggested that Engineers always obtain an estimate of efficiencies at the design conditions to ensure that equipment selections are in the best interest of the building owners and occupants.

Energy efficiency of ERV systems is often only considered at peak points in the design criteria, namely the design dehumidification day, winter heating day and summer cooling day. There are numerous periods throughout the year where an ERV system may in fact increase loads to the building envelope. In fact, current IECC code requires that ERV have bypass or control requirements to avoid adding load during these conditions. Although these periods are generally when a unit is not at peak capacity, they are an addition to the utility expense of a building, not a reduction. Many manufacturers implement a reduction in ERV wheel speed to meet this code requirement, however laboratory testing has shown that this increases EATR dramatically, leaving the user with an inefficient system, as well as increased health safety risks due to higher bypass of airborne contaminants. It should be noted that any exhaust air transferred back into the supply airstream will provide a perception of energy recovered, as such air is fully recovered, however notable studies by Georgia Tech and Carnegie Mellon Universities both identified that with ERV present, higher overall outdoor air supply airflows, up to 73%, were required to maintain a comparable indoor air quality as a building with low or no EATR (4).

Furthermore, the energy efficiency ROI calculations must take into consideration the added static pressure from additional exhaust and supply air filtration needs, and the desiccant wheel itself. The fan horsepower to overcome these static pressures is substantial, increasing fan energy consumption.

As a final point, exhaust return air conditions for many spaces are highly variable. As an example, a hotel with ERV may have extreme latent load and contaminant peaks during morning and evening hours from occupant bathing periods. Such daily swings in performance must be accounted for in both the economic evaluation and controls schema of a design. Many ERV operate statically and do not incorporate site specific considerations within their economic evaluation.

Conclusion:

The traditional return on investment calculations for inclusion of an ERV includes the following assumptions: The system has a balanced supply and exhaust return airflow, the operation of the ERV is always reducing the load of the corresponding HVAC system, maintenance expenses are minimal or not considered, no complexities are added to the system installation, and the Engineer has reduced cooling and heating capacity of the DOAU paired with the ERV.

Considering all the points herein, the prudent engineer should re-evaluate the use of ERV and only include them in mechanical design when they are safe, logical, and economical solutions for building owners and occupants. Current code offers many exceptions to the use of ERV, including those which are in the control of the engineer through fundamental building design decisions.

When possible, engineers should utilize barometric relief or powered exhaust fan roof ventilators with simplified duct runs, saving the user substantial economic and maintenance burden, and minimize the risk of air contaminants being reintroduced to the building.

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