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RESEARCH SUMMARY

Energy Recovery in Minnesota Commercial and Institutional Buildings: Expectations and Performance

BACKGROUND

Energy recovery ventilation (ERV) systems exchange heat and/or moisture between the outgoing exhaust air and the incoming outdoor (ventilation) air. These air-to-air ERVs are incorporated into mechanical ventilation systems and have the ability to reduce resulting heating and cooling loads. When operating according to design, it is possible for ERVs to use 10 to 100 times less energy than conventional heating and cooling systems, resulting in up to 80% energy savings on ventilation loads.

Despite their substantial energy efficiency potential, studies on as-operated energy recovery units are few, and expectations have been tempered by real world observations as anecdotal evidence suggests that as-operated performance may not live up to potential.

This project investigated the expectations and operating performance of ERV units in Minnesota commercial and institutional buildings. The project team used available data to characterize commercial and institutional ERVs in Minnesota, and then monitored the performance of representative ERV systems, identified and rectified problems that diminish ERV performance, and documented the energy use and costs associated with under-performing ERVs.

METHODOLOGY

This field investigation determined whether ERVs in commercial and institutional buildings are reaching their energy savings potential, documented the instances when they were not achieving expected savings, and resolved any issues that were preventing ERVs from performing at their full capacity. Basic demographic information about Minnesota ERVs was used to identify nine representative ERVs for long-term field assessment. Some existing data on the types of problems encountered with ERVs was consolidated to establish a field-based perspective on potential performance issues. The field work was organized to study and analyze representative ERVs, identify and resolve problems with ERV systems, and monitor post-resolution ERV performance. Measured field data were used to quantify existing unit energy recovery (the energy savings from ERVs), missed opportunities resulting from sub-optimal operation, and savings from recommissioned units.

The specific objectives were to:

1. Characterize ERVs in Minnesota commercial and institutional buildings.
2. Study a representative sample ERVs in detail.
3. Characterize and improve ERV performance.

RESULTS

Characterization

The research team analyzed data on 402 ERVs from 134 different buildings to understand basic system demographics. The analysis showed that the majority of buildings with energy recovery units also have multiple air handling systems, multiple energy recovery systems, and several ERVs of the same type. However, only a fraction of ventilation air is typically served by energy recovery, particularly in institutional buildings. Additional results from the characterization phase can be found below.

Commercial versus institutional buildings

- Institutional buildings hold 69% of all ERVs while commercial buildings hold 31% of ERVs (n = 101).
- The majority of institutional buildings with ERVs are K-12 schools at 51%, followed by higher education at 22% and various state and municipal facilities making up the balance.
- In commercial buildings, ERVs are distributed among a variety of buildings types that have above average ventilation loads including casinos, manufacturing and auto shops, assisted living facilities, labs, and sports and gym facilities.

Sizing breakdown

- The ERVs sampled here represent approximately 3,575,700 cfm of ventilation flow.
- ERV units range in size (outside air flow) from 215 cfm to 60,000 cfm, with an average flow rate of 9,510 cfm and a median flow rate of 5,945 cfm.
- One quarter of all ERV units are below 3,240 cfm and deliver less than 5% of the total flow while another quarter of units are rated above 11,030 cfm and deliver over 63% of the total flow.

- Although smaller units account for 75% of all systems, the majority of energy recovery comes from larger units over 10,000 cfm.

ERV system types

- There are three types of ERV systems identified in these data: enthalpy wheels (80%), plate heat exchangers (13%), and membrane plates (7%).
- Enthalpy wheels span the entire flow range, plate heat exchangers span a slightly narrower range (1,800 to 37,000 cfm), and membrane plates are sized at less than 1,200 cfm (with two exceptions).
- Enthalpy wheels tend to have the highest effectiveness, followed by membrane plates and fixed plate heat exchangers (with average effectiveness of 0.73, 0.66, and 0.64, respectively).

In summary, these data suggest that the most common scenario for air-to-air exhaust energy recovery in Minnesota is total enthalpy wheels in institutional buildings, most likely K-12 schools. ERVs are found in a variety of commercial building types with high ventilation loads. In both commercial and industrial buildings, the importance of large units to state-wide savings is striking — the top 25% of units are responsible for conditioning over 13 times the amount of ventilation air as the bottom quarter of units.

Expectations — Energy Recovery in Minnesota

There are several important performance observations with respect to energy savings and outside air temperature:

1. Half of all energy recovery in Minnesota occurs between about 12ºF and 45ºF.
2. Less than 10% of energy recovery occurs below -5ºF or above 85ºF.
3. Very little energy recovery takes place between 45ºF and 65ºF.

At a bare minimum, an ERV should be activated between 0ºF and 45ºF in order to realize between 60% and 80% of potential savings, and it should be activated above 80ºF to achieve peak cooling load reduction. The cumulative energy recovery for the nine units in this study is plotted as a function of outside air temperature in Figure 1 All ERVs fell within this range after recommissioning.

Figure 1 Cumulative energy recovery for nine ERV units in a TMY3 Minnesota climate

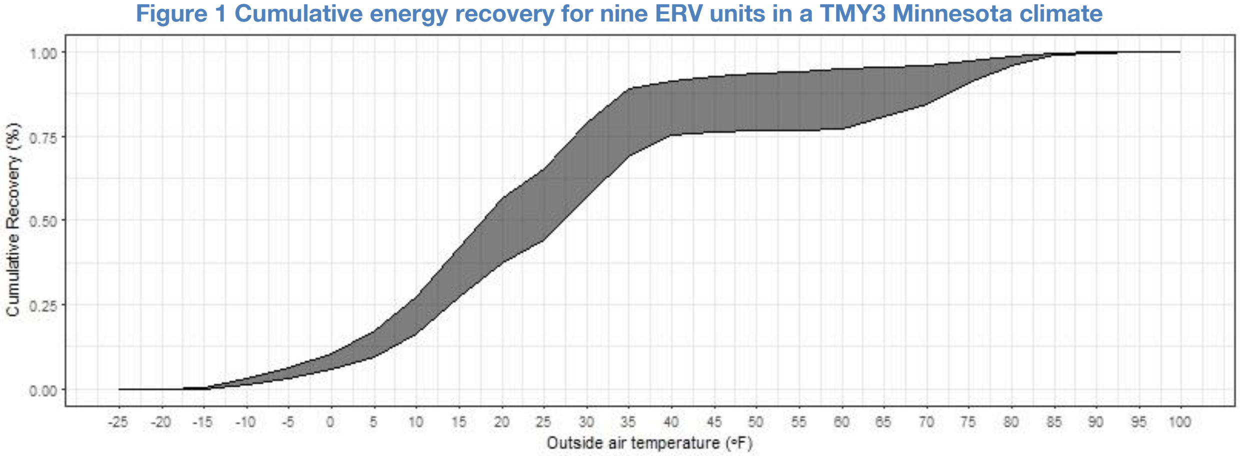
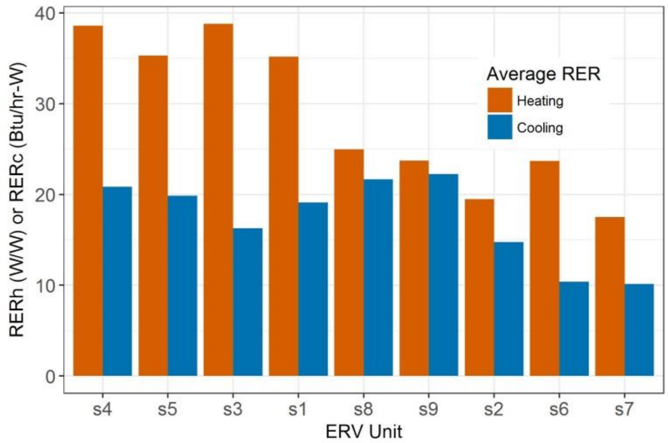


Figure 2 summarizes recommissioned ERV performance using the average recovery energy ratio (RER) for heating and cooling operation. The RER is the ratio of recovered energy to expended energy. There is an energy cost to running an ERV because added fan power is needed to push air through the unit and a motor is sometimes used to spin the unit. The RER offers a performance perspective that allows for a comparison to conventional heating and cooling systems. The RER for conventional heating equipment (natural gas heat) is about 0.8 W/W to 0.9 W/W, consistent with the typical efficiency of the heating systems. The RER for conventional cooling equipment has a broader range from about 10 Btu/hr-W to 30 Btu/hr-W for air and water cooled systems, respectively.

Figure 2: Average Recovery energy ratio (RER) for units in study



Although heating RER_h for ERVs are very large at design temperatures (100+ W/W), they are substantially reduced at mild temperatures when there is less recovery. The average heating RER_h in this study ranged from 17 to 39 W/W, suggesting ERVs are about 20 to 45 times more efficient than gas heating. In this study, these heating RER_h correspond to heating ventilation load reductions between 34% and 90%.

The high cooling RER_c (130 Btu/W-hr) often cited for design conditions are also reduced by a decrease in recovery during mild weather. Average cooling RER_c for ERVs ranges from 10 Btu/W-hr to 22 Btu/W-hr, which is on par or better than many conventional air conditioning systems. Most ERVs in this study did not have bypass, which effectively cut the cooling RER_c in half because these ERVs required extra fan power even during economizer mode. The cooling RER_c corresponds to about a 9% to 23% reduction in total cooling load. While cooling savings may be smaller than heating savings, these systems reduce peak cooling loads by up to 50% and thus provide a substantial benefit on top of the heating savings.

These performance metrics reinforce the notion that energy recovery in Minnesota's cold climate is a combination of heating energy savings and peak cooling load reduction.

Energy Savings from Recommissioning

Recommissioning the nine ERVs in this study resulted in savings of $17,168, or an increase in energy recovery of 42%. Eighty-three percent of the savings came from heating (gas) and 17% came from cooling (electric). Results varied greatly over the 9 units: 86% of the savings came from just two large units that were initially non-functional while two other units were already functioning such that no additional savings were found. The added savings summary from recommissioning the nine ERVs is shown in Table 1.

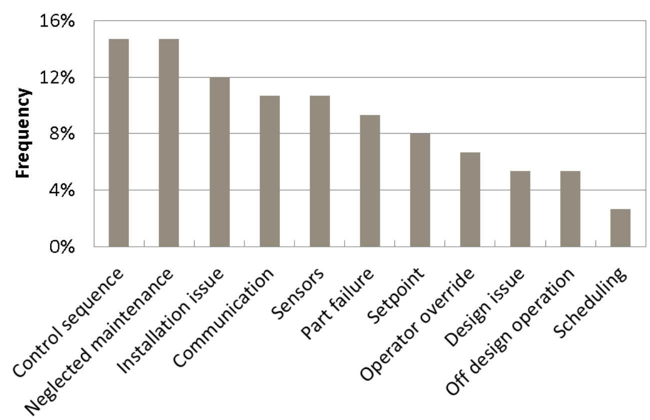
Table 1: Savings Summary

	New Gas Savings	New Gas Cost Savings	New Electric Savings	New Electric Cost Savings
	therms/yr	$/yr	kWh/yr	$/yr
Min	0	0	0	0
Max	4,721	5,852	2,805	2,234
Average	1,344	1,577	768	317
Median	772	631	511	25
Sum	12,099	14,197	6,916	2,853

Issues in ERV Systems

Through this field work, the project team identified and documented 75 different issues among the nine ERVs in the study. While the types of issues and their impact varied widely, they can be sorted into 11 different categories, as shown in Figure 3. About one third of the issues had major energy impacts, one third had only minor energy impacts, and about one third had no energy impact beyond diminishing the perception and expectations of ERVs.

Figure 3: Breakdown of 75 issues encountered



Issues in ERV Systems — Important Energy Penalties

About one third of the issues (24) were deemed to have significant energy impacts. Of those issues that did have an energy penalty, 21 reduced energy recovery during the heating season, increasing the ventilation load between 16 therms and 4,721 therms and increasing the gas costs between $13 and $3,857 annually. Sixteen issues increased the ventilation load during cooling season, which increased energy use between 67 kWh and 5,213 kWh and increased annual electrical costs between $7 and $584. Six issues relating to overrides, part failures, and installation prohibited energy recovery entirely. Several issues had very minor impacts and these included the adjustment of frost control sequences and the adoption of more aggressive frost control set points. Similar to frost control, economizer issues resulted in a lower energy impact than anticipated. The energy and cost penalties of the encountered issues are summarized in Table 2.

Table 2: Summary of energy and cost penalties of encountered issues

	Heating Penalty	Heating Cost Penalty	Cooling Penalty	Cooling Cost Penalty
	therms/yr	$/yr	kWh/yr	$/yr
Min	16	13	52	6
Max	4,721	3,857	5,213	584
Average	1,388	1,134	1,498	168
Median	698	571	813	91
Sum	27,756	22,676	23,963	2,684

RECOMMENDATIONS FOR CIP

Commissioning New Systems

This project demonstrated a strong need for commissioning new energy recovery systems. The persistence of dysfunctional ERVs as part of normal operations indicates a need for system installations to be validated immediately. Fifty percent of the found savings discovered would have been identified during a robust initial commissioning process.

Some general commissioning guidelines include:

1. Large ERV systems (10,000 cfm+) must be fully-commissioned.
2. Design flow rates (and subsequent savings estimates) need to be validated against as-operated flows.
3. Control sequences should follow ERV manufacturer recommendations and any deviations must be justified by project engineers.
4. Both control intent and detailed sequences need to be specified and as-implemented sequences verified by an accountable party.
5. Commissioning agents need to provide basic operator training to explain controls, warn about overriding controls, and offer guidance on when and how to verify ERV operation.

Improving Existing Systems

The majority of energy penalties that were found as a part of this project can be discovered and avoided if ERVs are touched by staff that are able to 1) identify when an ERV should be running and 2) assess whether an ERV is running. ERV problems often go unnoticed because there are usually no obvious operational implications, and thus it can be difficult to determine when an ERV is not operating. Validating an ERV system does not necessarily require a full recommissioning effort. For example, 60% to 80% of energy recovery occurs between 0ºF and 45ºF. Given this fact, a simple procedure to verify that an ERV is operational in this temperature range is an easy way to validate a majority of savings. Beyond basic operational validation, a dedicated recommissioning effort may be needed to achieve additional savings opportunities.

Targeted Recommendations

Design Engineers need to provide more rigorous specifications with regard to the control of energy recovery systems.

Mechanical and controls contractors need to follow engineer specifications and push-back against engineers that do not provide complete specification. Technicians are not responsible for making improvisational decisions on sensing and control.

Commissioning agents need to ensure knowledge transfer about system intent (including control) as well as design-based expectations for ERV performance. They have to validate sequencing and document instances where as-operated conditions differ significantly from design.

Owners need to provide resources for operators to understand systems they administer. Owners should establish protocols and ensure that operators are able to perform semi-annual operational checks on ERV systems.

CONCLUSION

Over the last 20 years, air-to-air exhaust energy recovery systems have become more common in Minnesota commercial and institutional buildings because of their potential for cost-effective energy efficiency benefits. While ERVs are in fact capable of achieving impressive savings of up to 80% of the ventilation air heating load, steps must be taken to ensure that units are installed and operated according to specification to reach performance expectations. Performance expectations should consider that practical implementation choices and performance under mild conditions will diminish savings with respect to design figures.

A general lack of understanding around ERV performance has led to bad experiences with ERVs and their associated systems, leading to negative perceptions and diminished expectations. However, these experiences and perceptions generally have little to do with the energy efficiency performance, but more so around the typical processes involved with implementing the technology.

Mistakes relating to part failures, operator overrides, and installation account for 75% of the lost energy recovery. These mistakes persist due to unfamiliarity among operations staff and controls technicians as well as the absence of system feedback from poorly functioning ERVs. Fortunately, these mistakes can be easily corrected by commissioning new units to ensure that they function properly from the start. Problems with existing ERV systems can be easily identified by staff that is trained to understand ERVs and assess their operation.

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