Laboratory Evaluation of Energy Recovery Ventilators

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Building America-Partnership for Improved Residential Construction (BA-PIRC)

November 2016

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Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

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NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40339-02

November 2016

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Acronyms and Abbreviations

AC	air conditioning
ANSI	American National Standards Institute
AHRI	Air-Conditioning, Heating and Refrigeration Institute
BA	Building America
BA-PIRC	Building America-Partnership for Improved Residential Construction
CFM	cubic feet per minute
CSA	Canadian Standards Association
ERV	energy recovery ventilator
FSEC	Florida Solar Energy Center
GTI	Gas Technology Institute
gr/lb	grains per pound
HVAC	heating, ventilating, and air conditioning
IAQ	indoor air quality
kW	kilowatts
lbm	pounds mass
NREL	National Renewable Energy Laboratory
Pa	pascals
PARR	Partnership for Advanced Residential Retrofit
SCFM	standard cubic feet per minute, where standard conditions are defined as a temperature of 68°F (20°C) and an absolute pressure at sea level of 14.696 psi or 29.92 in. Hg (101.325 kPa)

Executive Summary

Over the years, building scientists have characterized the relationship between building airtightness, exhaust-only appliances airflows, and building depressurization. Now, as the use of deep retrofit measures and new construction practices is growing to realize lower infiltration levels in increasingly tighter envelopes, performance issues can arise with the operation of exhaust-only appliances in depressurized homes. As the depressurization levels climb in tighter homes, many of these exhaust-only appliances see their rated airflows reduced and other related performance issues arise as a result. If sufficiently depressurized, atmospherically vented combustion appliances that may be present in the home can "backdraft" as well. Furthermore, when exhaust-only appliances operate and a tight home becomes depressurized, water vapor intrusion from outdoors in more humid climates can raise the additional issue of mold in the building envelope.

The use of energy recovery ventilators (ERVs) in tight homes in mixed-humid and hot-humid climates is already practiced. Unbalancing the ERV by reducing exhaust airflows can provide a means to supply make-up air and reduce the level of home depressurization to mitigate these issues, helping the homeowner realize the rated performance of the exhaust-only appliances, achieve safe operation of atmospherically vented combustion, provide the necessary level of fresh ventilation air, and improve envelope durability. Unbalanced operation of the ERV to address depressurization can obviously result in unintended consequences in other areas, such as further loss of humidity control in homes in more humid climates.

In such tight-home scenarios, it is expected that ERVs will operate a substantial amount of time in unbalanced mode with much higher supply than exhaust airflows. Although ERV design performance under balanced flow conditions is well documented, there is no information in the public domain that empirically establishes the effect of unbalanced flow on sensible and latent exchange, especially in the now dominant membrane-type ERV used in residential applications. Therefore, in the task reported here, Gas Technology Institute (GTI) focused on a laboratory evaluation of the unbalanced flow (lowered exhaust airflow) performance of the RenewAire model EV 200, a membrane-type ERV delivering 200 standard cubic feet per minute (SCFM) of supply air.

The tests conducted by GTI show significant variation in ERV effectiveness at different levels of unbalanced airflows. Keeping supply airflow constant and lowering exhaust airflow increases effectiveness of both latent and sensible heat exchange. However, the increased effectiveness is accompanied by reduced capacity for load removal from the supply air, resulting in increased load to the conditioned space. Under decreasing exhaust airflow conditions, sensible load effectiveness exceeded a value of 1 under two sets of testing conditions. This was a result of the temperature rise of the supply air passing through the ERV augmented by the effect of motor heat gain, cross leakage heat gain, and casing heat gain. Consequently, measured sensible effectiveness must be qualified as the so-called Apparent Sensible Effectiveness of the ERV unit (which is the term used in the Canadian Standards Association C439 standard for testing ERVs).

The data set generated during the tests yielded a limited set of curve fit algorithms for unbalanced flow performance that can be used to supplement current modeling approaches in simulation tools like EnergyPlus. Building America teams can then use such models to analyze whole-house effects and determine best practices for unbalanced ERV operations.

The U.S. Department of Energy's (DOE) Building America (BA) Program has been a source of innovations in residential building energy performance, durability, quality, affordability, and comfort for more than 15 years. This world-class research program partners with industry (including many of the top U.S. homebuilders) to bring state-of-the-art building innovations and resources to market. Note that the research in this report was conducted in 2012, so some aspects may appear dated. There was an administrative delay in printing the work.

1 Problem Statement

As deep retrofit measures and new construction practices are applied to realize lower infiltration levels in increasingly tighter homes, performance issues arise with the operation of exhaust-only appliances throughout the home (Bliss 2005). Furthermore, when exhaust-only appliances operate and the tight home becomes depressurized, water vapor intrusion from outdoors in more humid climates raises the additional issue of mold in the building envelope (Trechsel 2001). The use of energy recovery ventilators (ERVs) in tight homes in mixed-humid and hot-humid climates is already practiced (Moyer et al. 2004). "Unbalancing" the ERV—reducing its exhaust airflow while maintaining higher supply airflows—provides a means to deliver make-up air and reduce the level of home depressurization to mitigate these issues, as well as bring in needed ventilation air.

In such scenarios, it is expected that ERVs will operate a substantial amount of time in unbalanced mode with much higher supply than exhaust airflows. Currently, ERVs do not have specific design features to actively accommodate unbalanced flow operation. Future designs may include some forms of house pressure-activated switch, exhaust fan interlock, or variable drive ERV motor or motors. Although ERV design performance under balanced flow conditions is well documented, there is no information in the public domain that empirically establishes the effect of unbalanced flow on sensible and latent exchange, especially in the now dominant membrane-type ERV used in residential applications. The performing contractor for this work, the Gas Technology Institute (GTI), focused its laboratory testing on a RenewAire model EV 200, membrane-type ERV delivering 200 SCFM of supply air. The data set generated during the evaluation yielded a limited set of curve fit algorithms for unbalanced flow performance that others can use to supplement current modeling approaches in simulation tools like EnergyPlus. BA teams can then use such models to analyze whole-house effects and determine best practices associated with unbalanced ERV operations.

1.1 Background

An ERV is a device that exchanges heat and moisture between two airstreams: one exiting the home (exhaust air) and one entering the home (supply air). Residential ERVs almost exclusively now use a membrane to achieve the sensible and latent heat transfer between the two airstreams. During colder weather, the ERV exhaust air warms and moistens the supply air from outdoors. During warmer weather, the ERV exhaust air cools and dries the supply air from outdoors. An ERV photo and schematic are shown in Figure 1 and Figure 2.

Figure 1. Photograph of RenewAire ERV Model EV 200 with door open
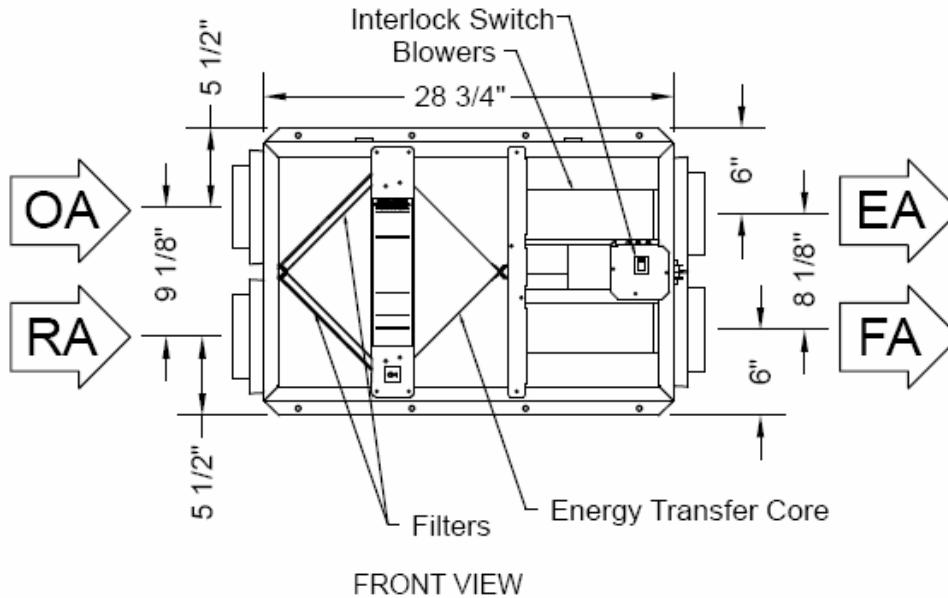
Figure 2. Dimensions of RenewAire ERV Model EV 200

EA = exhaust air, FA = fresh air, OA = outdoor air, RA =return air

Over the years, building scientists have characterized the relationship between building airtightness, exhaust airflows, and building depressurization. One such embodiment (Figure 3) (Bliss 2005), shows a home's CFM50 value from a blower door test on the horizontal axis, the total exhaust airflow CFM from bath and kitchen fans, a clothes dryer, and all other exhaust-only appliances on the vertical axis, and the resulting depressurization in pascals plotted across the chart estimated by this relationship for depressurization:

Depressurization (Pa) = 50 * (CFMfans/CFM50)^(1/0.65).
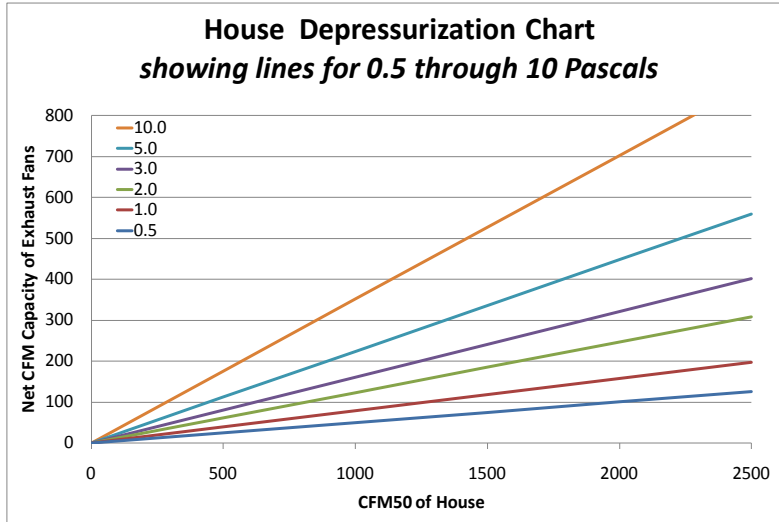
Figure 3. House depressurization levels

The unbalanced operation of an ERV can shift house depressurization levels downward by supplying make-up air and reducing the net CFM capacity of an exhaust fan. Figure 4 shows how providing 150 CFM of make-up air through an ERV (e.g., unbalanced flow of 200 CFM supply and 50 CFM exhaust) could potentially lower a 1,000 CFM50 home with an original 300 CFM of exhaust fans to a net 150 CFM. In doing so, the home could drop from eight pascals to under three pascals of depressurization, which represents a significantly more desirable level of depressurization for realizing exhaust-only appliance rated performance and achieving safe atmospherically vented combustion.

The unbalanced operation of the ERV to address depressurization can obviously result in unintended consequences in other areas, such as further loss of humidity control in homes in more humid climates. The performance mapping that GTI performed of the sensible and latent exchange of the ERV over the selected range of possible unbalanced operation provides BA researchers with additional modeling algorithms that could supplement current ERV modeling approaches in simulation tools such as EnergyPlus. The findings, although limited to three distinct operating conditions, help in the analysis of the resulting effect on temperature and humidity control, air conditioner (AC) energy use, and other quantitative attributes of the whole-house performance with and without unbalanced ERV operation. With these resulting effects quantified, additional informed judgments can also be made regarding associated benefits and risks for exhaust-only appliance operation at lower and higher depressurization levels, with and without unbalanced ERV operation respectively.

House Depressurization Chart
showing 150 CFM reduction in net exhaust
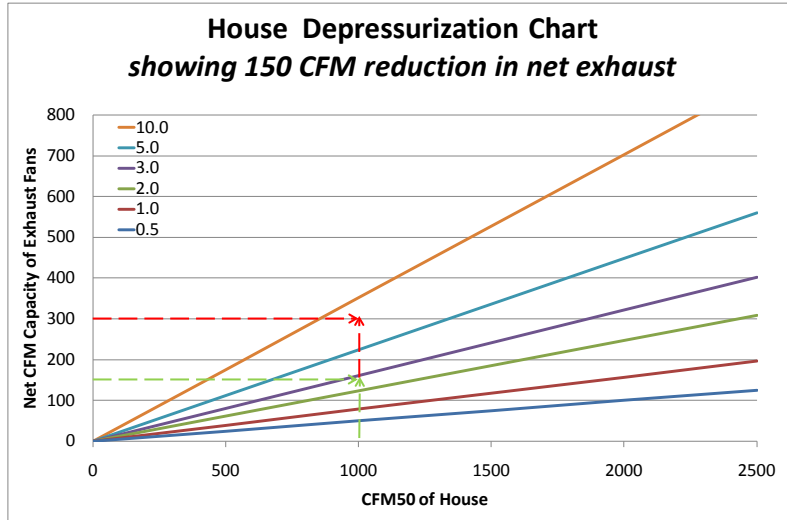
Figure 4. House depressurization levels with make-up air

1.2 Relevance to Building America's Goals

This work targets the growing number of homes using "deep retrofit" measures and new construction practices to realize sufficiently lower infiltration levels that require mechanical ventilation as prescribed by ASHRAE Standard 62.2, Ventilation for Acceptable Indoor Air Quality (IAQ) in Low-Rise Residential Buildings (ASHRAE 2007). BA teams are exploring approaches to meet both energy use reduction goals and these prescriptive IAQ requirements in mixed-humid and hot-humid climates. Use of ERVs to introduce fresh air while mitigating sensible and latent heating, ventilating, and air conditioning (HVAC) loads is one approach to meeting the goals (Moyer et al. 2004).

As infiltration levels are lowered in increasingly tighter homes, performance issues can arise in the operation of exhaust-only appliances throughout the home. Furthermore, when exhaust-only appliances operate and the tight home becomes depressurized, water vapor intrusion from outdoors in more humid climates could raise additional issues of mold in the building envelope. The use of ERVs in tight homes in mixed-humid and hot-humid climates is already practiced. Unbalancing (reducing exhaust airflows) of the ERV could provide a means to supply make-up air and reduce the level of home depressurization to mitigate these issues.

In the task reported here, GTI's ERV evaluation yielded a limited set of curve fit algorithms for unbalanced flow performance that can be used to improve the simulations of ERVs in analysis tools like EnergyPlus. Based on this completed task work, BA teams can then use such enhanced models to analyze whole-house effects and determine best practices associated with unbalanced ERV operations to mitigate depressurization issues. Ultimately, that analysis will provide further insight into how widely such ERV practices could apply to homes, especially in mixed-humid and hot-humid climates.

1.3 Cost Effectiveness

As building envelope energy efficiency measures have been applied to increasingly tighter homes, mechanical ventilation has become necessary to compensate for the reduction in natural infiltration and to maintain acceptable IAQ. Such prescriptive mechanical ventilation requirements for acceptable IAQ, identified in ASHRAE Standard 62.2, Ventilation for Acceptable Indoor Air Quality (IAQ) in Low-Rise Residential Buildings (ASHRAE 2007), require some means of mechanical ventilation, which has become an unavoidable first cost and operating cost addition in such tight homes. In recent years, BA researchers and other researchers have been evaluating the most cost-effective options for mechanical ventilation. Mechanical ventilation options have generally been represented in the past as exhaust-only, supply-only, and balanced systems. In mixed-humid and hot-humid climates, application of these mechanical systems must take into account:

1. ASHRAE Standard 62 ventilation rates

2. Humidity control levels

3. House depressurization levels.

BA teams have addressed the first two issues in hot-humid climates in past research, and researchers at the Florida Solar Energy Center (FSEC) (Moyer et al. 2004) have stated, "a comprehensive ventilation approach requires not only air exchange but also indoor humidity control." The FSEC researchers evaluated many of the exhaust-only, supply-only, and balanced mechanical ventilation system options in their research house and compared resulting ventilation rates and humidity control levels. They also measured—but did not report in Moyer et al. (2004) — pressure differences across the research house envelope. The operating costs of the different mechanical ventilation systems were normalized and determinations made regarding relative cost effectiveness.

Only balanced ERV system options were investigated by FSEC. Completion of GTI's laboratory evaluation of unbalanced ERV operation provided performance maps and algorithms for others to enhance annual simulations and establish initial best practice specifications for an unbalanced ERV operation to address all three issues, including house depressurization levels. FSEC can then implement such an unbalanced ERV operation in their research house using their past testing protocols and establish its resulting ventilation rates, humidity control levels, envelope pressure differences, and operating costs that could be normalized for inclusion in the past determinations of relative cost effectiveness with all the other mechanical ventilation system options.

1.4 Tradeoffs and Benefits

A home today can have several appliances exhausting simultaneously, including:

- Bath exhaust fans between 25 CFM and 100 CFM

- Kitchen hoods between 100 CFM and 400 CFM

- Clothes dryers around 150 CFM.

The total flow can easily equal 300 CFM or more and result in significant depressurization of a tighter home as shown previously in Figures 3 and 4. As the depressurization levels climb in tighter homes, many of these exhaust-only appliances see their rated airflows reduced and other related performance issues arise as a result. If sufficiently depressurized, atmospherically vented combustion appliances such as furnaces and water heaters could "backdraft" as well. Many home energy auditors, contractors, and weatherization program administrators cite house depressurization limits for combustion safety (BPI 2005). Some depressurization limits are as low as -3 pascals (Pa) for orphaned water heaters, and often reference well-established procedures for determining the safety of residential chimneys (CMHC 1988).

Furthermore, when exhaust-only appliances operate and a tight home becomes depressurized, water vapor intrusion from outdoors in more humid climates could generate the additional issue of mold in the building envelope. It is desirable to achieve neutral or even positive pressurization in buildings to limit moisture movement through the envelope. This cannot be readily realized in houses, but it is a growing practice in commercial and institutional buildings in more humid climates (Trechsel 2001).

The operation of all these exhaust-only appliances in conjunction with the mechanical ventilation system raise significant issues related to (1) occupant comfort, health, and safety and (2) building and equipment durability and reliability. "Unbalancing" an ERV—reducing its exhaust airflow while maintaining higher supply airflows—could provide a means to deliver make-up air and reduce the level of home depressurization to mitigate these issues. Optimum design would feature variable unbalancing controlled by level of home depressurization.

2 Experiment

The laboratory evaluation of unbalanced ERV operation addresses—and answers—the following research questions:

- What are the sensible and latent effectiveness values of a membrane-based ERV over the full range of possible unbalanced operation (i.e., "actively" stepping down from 100% to 25% exhaust airflow while at 100% supply airflow)?

- What is the impact of ERV unbalancing on its capacity to condition supply air entering the building?

- How does unbalanced operation of the ERV affect its electric energy consumption?

2.1 Technical Approach

The unbalanced ERV tests were performed according to applicable requirements of standard ANSI/AHRI Standard 1060-2005 "Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation" (AHRI 2005). ANSI/AHRI Standard 1060-2005 applies specifically to the ERV heat exchanger component, while the unbalancing tests were run on a complete ERV unit. However, the team conducting the evaluation determined the three factors that constitute the standard's definition of performance—total, sensible, and latent effectiveness—were the most appropriate indicators of the impact that unbalanced flow may have on a complete ERV system installed in a building, as these three factors match the types of performance indicators used in modeling tools like EnergyPlus.

The tests were conducted in GTI's Air Treatment Technology test loop that can control and monitor the airflow rates and psychrometric conditions of all four inlet/outlet streams of tested HVAC equipment. The test loop was located in a climate-controlled space with preconditioning to maintain required inlet temperatures, humidities, and airflow rates for performance evaluations at prescribed psychrometric test points. ERV state point conditions were monitored and sampled data recorded on a network-based data acquisition system. The configuration of the test loop, including location and type of instrumentation, is provided in Figure 5.[1]

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[1] Table 3 (Section 2.4) provides additional information on instrumentation and measurement accuracy.

In this evaluation, the test loop was used to assess performance impacts of unbalanced ERV function when operated to provide make-up air for exhaust-only appliances in homes. The ERV operation was augmented with loop variable speed fans operation along with other features necessary for the full range of unbalanced operation and the unit integration with the GTI test loop. Testing concentrated on evaluation of a fully ducted (four duct collars), membrane-type RenewAire ERV model EV 200 (Figures 1 and 2) that can deliver up to 200 SCFM of conditioned air 0.2" of water head pressure.
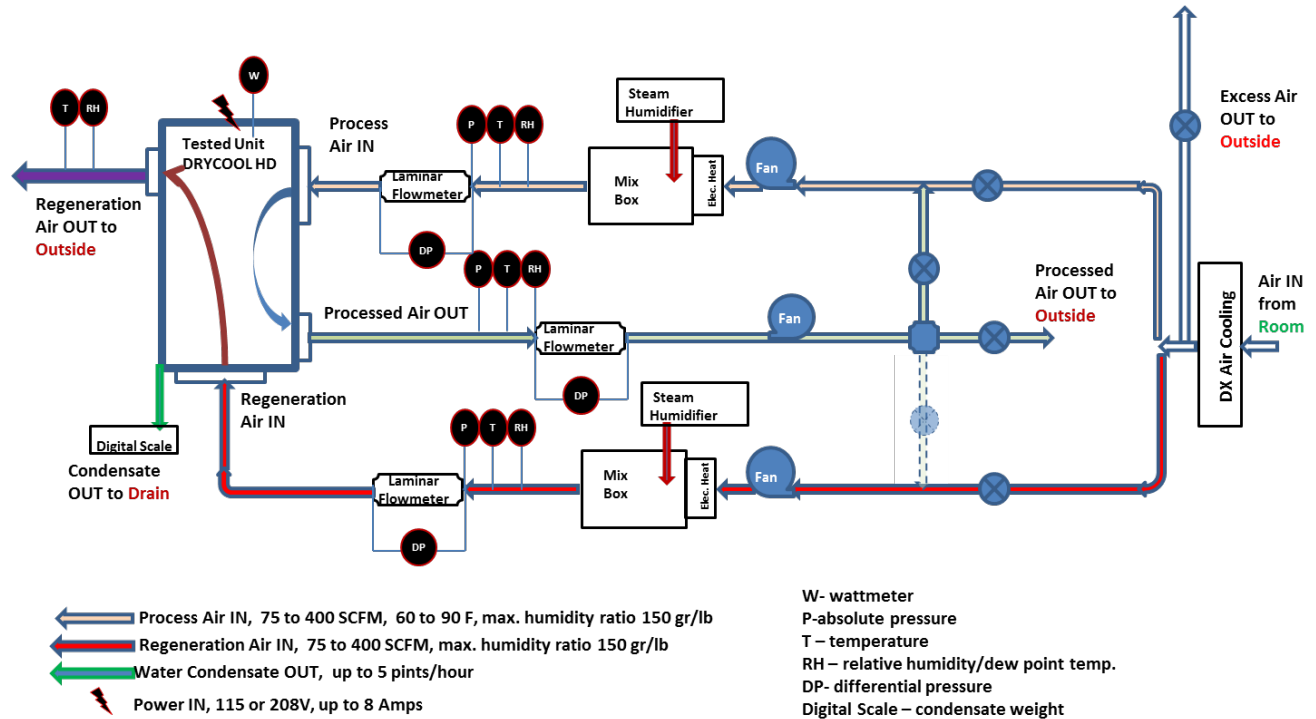
Figure 5. ERV test loop configuration and placement of measurement points

dx = direct expansion

The GTI test plan was coordinated and finalized with Dane Christensen of the National Renewable Energy Laboratory (NREL), who in 2012 was conducting ERV tests concentrating on creating performance maps for sensible and latent effectiveness, at a single balanced airflow. Although these NREL laboratory evaluations and several field investigations have started generating performance algorithms, unbalanced ERV performance remained unaddressed.

2.2 Measurements

The following performance parameters were evaluated for the tested RenewAire ERV model EV 200:

1. Total Effectiveness: TotEff , non-dimensional

2. Sensible Effectiveness: SensEff , non-dimensional

3. Latent Effectiveness: LatEff , non-dimensional

4. Mass Balance: %

5. Sensible Energy Balance: %

6. Latent Energy Balance: %

7. Total Load Reduction of Supply Air: TotCap, kilowatts (kW)

8. Sensible Load Reduction of Supply Air: SensCap, kW

9. Latent Load Reduction of Supply Air: LatCap, kW

10. Pressure Drop of Supply and Exhaust airflows at standard conditions, SDPs and EDPs, inch H2O (at selected test set point)

11. Airflow of Supply and Exhaust: Supply Air Flow and Exhaust Air Flow, SCFM

12. Power Consumption: WattIn, Watts

These performance parameters were evaluated at three different supply air (SA) conditions and three exhaust air (EA) conditions: EA1, EA2, and EA3 (see Figure 6).
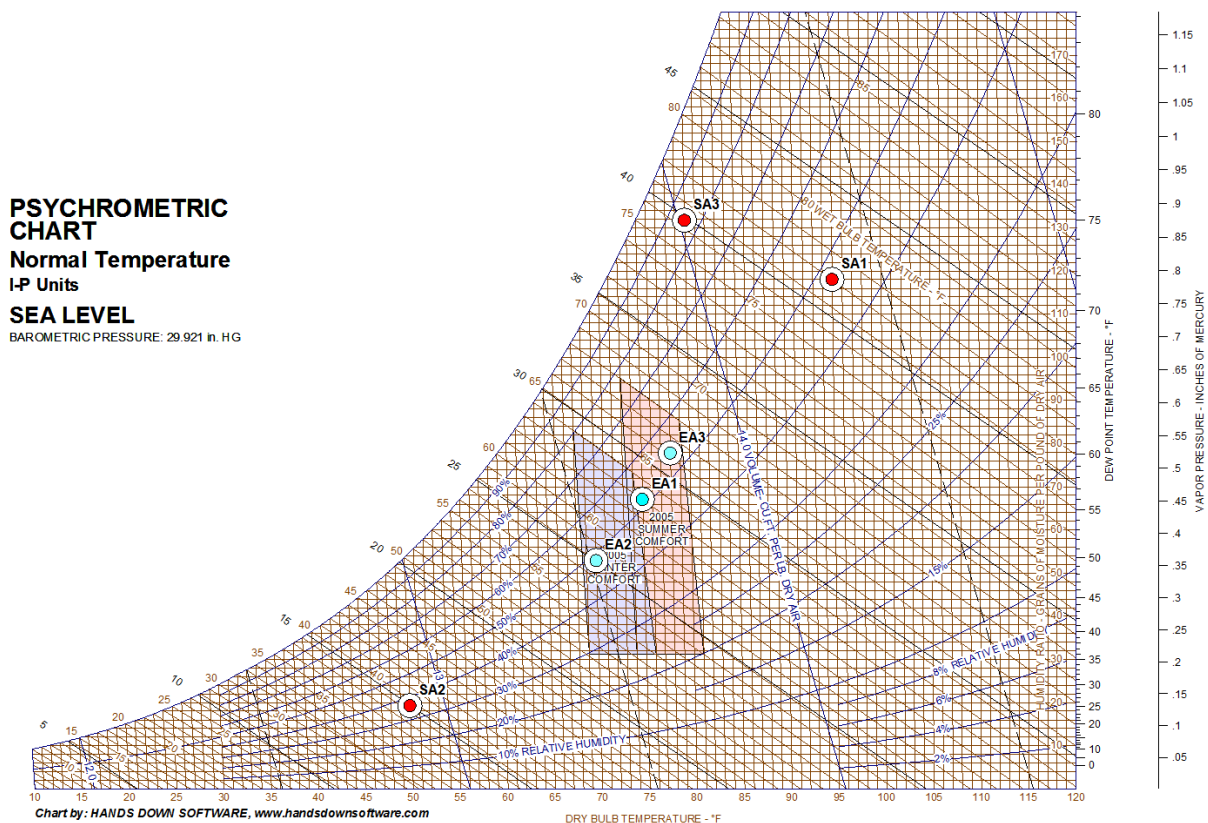
Figure 6. Location ERV test point air condition on psychometric chart

Two of the three EA test conditions followed ANSI/AHRI Standard 1060-2005 EA heating and cooling points specification while the third was selected to represent real residential application exhaust air conditions (higher dry bulb temperature of 78°F and relative humidity of 54%.)

The SA test conditions followed ANSI/AHRI Standard 1060-2005 SA cooling points specifications and a modified heating point condition[2] while the third was selected to approximate an ASHRAE 1% dew point design condition for a high humidity location more typical of a southeast U.S. location.

Table 1 shows the how the three selected sets of test conditions were defined.

Table 1. Supply and Exhaust Air Test Conditions

Conditions	Supply Air		Exhaust Air		Test Points[a]
	Dry Bulb (°F)	Dew Point (°F)	Dry Bulb (°F)	Dew Point (°F)	
Standard 1060–2005 SA cooling point conditions	95	71.9	75	56.2	1–4
ANSI/AHRI Standard 1060-2005 SA modified heating point conditions	50	25.0	70	49.8	5–8
High Outdoor Humidity Conditions	80	75.0	78	60°	9–12

See Table 2 and Table 3.

As shown in Tables 2 and 3, EA flow rates varied during testing from nominal or 100% to 75%, 50%, or 25% of nominal flow, while SA was kept at 100% of nominal flow. The total matrix of test points for the evaluated unit was twelve conditions, which is commensurate with the limited budget of this task.

The above tests were intended to encompass likely "active" approaches to unbalancing ERV operation. Such large reductions in exhaust-only airflows were accomplished in the laboratory by actively controlling flow rates using external fans in the test loop. In actual field applications, reductions in exhaust-only airflows could be accomplished by actively modulating down the ERV's fan curve with a variable or step speed motor, and the reductions could be completed in some kind of interlocked control scheme with exhaust-only appliances. To date, there is no commercial version of an ERV with active control of unbalanced flow.

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[2] ANSI/AHRI Standard 1060-2005 SA heating point conditions of dry bulb temperature 35°F and dew point temperature of 30.3°F were altered to represent a warmer but drier climatic condition with a dry bulb temperature 50°F and dew point temperature of 25°F. This change resulted from the need to adapt to the higher minimum temperature limitation of the test loop as well as an interest in testing the ERV unbalanced mode with very dry supply air to explore performance sensitivities.

Table 2. Supply Air Test Point Conditions

Test #	Supply Air IN Test Point	SCFM	Dry Bulb (°F)	Wet Bulb (°F)	Dew Point (°F)	Relative Humidity (%)	Humidity Ratio (gr/lb)
1	SA1	Nominal	95.0	78.0	71.9	47.5	121.2
2	SA1	Nominal	95.0	78.0	71.9	47.5	121.2
3	SA1	Nominal	95.0	78.0	71.9	47.5	121.2
4	SA1	Nominal	95.0	78.0	71.9	47.5	121.2
5	SA2	Nominal	50.0	39.5	25.0	36.0	19.1
6	SA2	Nominal	50.0	39.5	25.0	36.0	19.1
7	SA2	Nominal	50.0	39.5	25.0	36.0	19.1
8	SA2	Nominal	50.0	39.5	25.0	36.0	19.1
9	SA3	Nominal	80.0	76.3	75.0	84.8	131.8
10	SA3	Nominal	80.0	76.3	75.0	84.8	131.8
11	SA3	Nominal	80.0	76.3	75.0	84.8	131.8
12	SA3	Nominal	80.0	76.3	75.0	84.8	131.8

Table 3. Exhaust Air Test Point Conditions

Test #	Exhaust Air IN Test Point	SCFM	Dry Bulb (°F)	Wet Bulb (°F)	Dew Point (°F)	Relative Humidity (%)	Humidity Ratio (gr/lb)
1	EA1_100	Nominal	75.0	63.0	56.2	51.9	68.9
2	EA1_75	0.75 Nom.	75.0	63.0	56.2	51.9	68.9
3	EA1_50	0.5 Nom.	75.0	63.0	56.2	51.9	68.9
4	EA1_25	0.25 Nom.	75.0	63.0	56.2	51.9	68.9
5	EA2_100	Nominal	70.0	58.0	49.8	48.7	54.4
6	EA2_75	0.75 Nom.	70.0	58.0	49.8	48.7	54.4
7	EA2_50	0.5 Nom.	70.0	58.0	49.8	48.7	54.4
8	EA2_25	0.25 Nom.	70.0	58.0	49.8	48.7	54.4
9	EA3_100	Nominal	78.0	66.2	60.0	53.9	77.6
10	EA3_75	0.75 Nom.	78.0	66.2	60.0	53.9	77.6
11	EA3_50	0.5 Nom.	78.0	66.2	60.0	53.9	77.6
12	EA3_25	0.25 Nom.	78.0	66.2	60.0	53.9	77.6

2.3 Equipment

The major instrumentation in the GTI test loop that was used in the ERV evaluation is described in Table 4. For the specific location of measurement points, see Figure 5.

Table 4. Measured Parameters and Instrumentation Details

Measurement	Equipment Used	Make	Model
Flow rate	3 x laminar flowmeter, 75–400 SCFM, accuracy +/- 2.5% of reading	Meriam Process Technologies	50MC Series Laminar Z50MC2-6
Absolute pressure	3 x absolute pressure transmitter, atmospheric + 10 inch H20, accuracy +/- 1% of reading	Honeywell	ST3000 Smart Pressure Transmitter STA92L-E1G
Differential pressure	3 x differential pressure transmitter, 0–4 inch H20, +/- 1% of reading	Honeywell	ST3000 Smart Pressure Transmitter STD110-E1H
Temperature	4 x temperature measurement arrays, 32ºF to 100ºF, accuracy +/- 0.5ºF	Omega	Ultra Precise RTD P-L-1/10-1/8-6-0-P-3
Moisture	4 x Dew point/ relative humidity moisture analyzer, accuracy +/- 0.5ºF dew point	General Eastern	Chilled Mirror Optisonde 1-1-1-1-1-1-1-0
Electric power consumption	1 x wattmeter, single phase 115V 8A and 208V 8A, +/- 1% of reading	Hotec Tech. Inc.	Power Transmitter ITL-1010-1

3 Analysis

As noted, the tests were performed to conform to applicable guidelines of ANSI/AHRI Standard 1060-2005 "Performance Rating of Air-to-Air Exchangers for Energy Recovery Ventilation." Instead of typical sensible and total effectiveness, a so-called Apparent Sensible and Total Effectiveness was calculated. The term Apparent Effectiveness is used in the CSA C439 standard for testing ERVs to describe the temperature rise of the outdoor air passing through an ERV. The effectiveness includes the effect of motor heat gain, cross leakage gain, and casing gain. It is numerically higher than the sensible or total recovery efficiency of the ERV. The Apparent Sensible, Latent and Apparent Total Effectiveness as well as Mass and Energy Balances of the tested air-to-air ERV were calculated using the following equations:

- **Apparent Total Effectiveness (-)**

  Abs(TotEff)= (SMFOut *(SHIn - SHOut))/(MinMF*(SHIn - EHIn))

- **Apparent Sensible Effectiveness (-)**

  Abs(SensEff) = (SMFOut * (SDBIn - SDBOut))/(MinMF*(SDBIn - EDBIn))

- **Latent Effectiveness (-)**

  Abs(LatEff) = (SMFOut * (SWIn - SWOut))/(MinMF*(SWIn - EWIn))

- **Mass Balance (%)**

  MassFlowBal = 1- ((SMFOut + EMFOut)/(SMFIn+EMFIn))

- **Sensible Energy Balance (%)**

  SensEnerBal = 1- ((SMFOut * SDBOut * (0.24 + SWOut * 0.444))   + (EMFOut * EDBOut * (0.24 + EWOut * 0.444))) / ((SMFIn * SDBIn * (0.24 + SWIn * 0.444))   + (EMFIn * EDBIn * (0.24 + EWIn * 0.444)))

- **Latent Energy Balance (%)**

  LatEnerBal = 1- ((SMFOut *1061 * SWOut) + (EMFOut *1061 * EWOut)) / ((SMFIn *1061 * SWIn) + (EMFIn *1061 * EWIn))

In addition—although it is not listed in the ANSI/AHRI Standard 1060-2005 it is interesting to the end user—performance parameters showing how much of the Sensible, Latent and Total Supply Air Load Reduction can be provided by the ERV were calculated using the following equations shown:

- **Total Load Reduction Capacity of Supply Air (kW)**

  TotCap = (SMFOut * (SHIn - SHOut)) * (60/3412)

- **Sensible Load Reduction Capacity of Supply Air (kW)**

  SensCap = SMFOut * ((SDBIn * (0.24 + SWIn*0.444)) - (SDBOut * (0.24 + SWOut*0.444))) * (60/3412)

- **Latent Load Reduction Capacity of Supply Air (kW)**

  LatCap = (SMFOut *1061 *(SWIn - SWOut)) * (60/3412)

Where:

SMFOut = Supply Air Mass Flow leaving ERV/delivered to building, lb/h
EMFIn = Exhaust Air Mass Flow leaving building/entering ERV, lb/h
MinMF = Minimum of SMFOut and EMFIn values
SMFIn = Supply Air Mass Flow entering ERV, lb/h
EMFIn = Exhaust Air Mass Flow leaving ERV, lb/h
SDBIn = Supply Air IN Dry Bulb temp, deg F
SDBOut = Supply Air OUT Dry Bulb temp, deg F
SWIn = Supply Air IN Absolute Humidity ratio, lb H2O/lb dry air
SWOut = Supply Air OUT Absolute Humidity ratio, lb H2O/lb dry air
SHIn = Supply Air IN Enthalpy, Btu/lb
SHOut = Supply Air OUT Enthalpy, Btu/lb
EDBIn = Exhaust Air IN Dry Bulb temp, deg F
EDBOut = Exhaust Air OUT Dry Bulb temp, deg F
EWIn = Exhaust Air IN Absolute Humidity ratio, lb H2O/lb dry air
EWOut = Exhaust Air Out Absolute Humidity ratio, lb H2O/lb dry air
EHIn = Exhaust Air IN Enthalpy, Btu/lb

The pressure drop of supply and exhaust airflows of the tested air-to-air ERV equipment at standard conditions were calculated using the following equations:

- **Supply Air Pressure Drop at standard conditions**

  SDPs = SDP * (SD/SDs)*(SUs/SU)

- **Exhaust Air Pressure Drop at standard conditions**

  EDPs = EDP * (ED/EDs)*(EUs/EU)

Where:

SDP = Supply Air Pressure Drop, in H2O
SD = Supply Air Density as tested, lbm/ft^3
SDs = Supply Air Density at standard conditions, lbm/ft^3
SU = Supply Air Viscosity as tested, lbm/ft^2 h
SUs = Supply Air Viscosity at standard conditions, lbm/ft^2 h

EDP = Exhaust Air Pressure Drop, in H2O
ED = Exhaust Air Density as tested, lbm/ft^3
EDs = Exhaust Air Density at standard conditions, lbm/ft^3
EU = Exhaust Air Viscosity as tested, lbm/ft^2 hEUs = Exhaust Air Viscosity at standard conditions, lbm/ft^2 h

- **Volumetric Airflow of Supply and Exhaust**, Supply Air Volumetric Airflows (SVFs) and Exhaust Air Volumetric Airflows (EVFs) in SCFM were calculated using Meriam Flowmeter Technical Documentation algorithms (Meriam Instrument n.d.).

- **Power Consumption**, WattIn, was recorded directly from the laboratory Wattmeter.

4 Results

Detailed test results for the RenewAire ERV model EV 200 are included in Appendix A. The unit was operated as close as possible to the manufacturer-rated 200 SCFM supply airflow rates while the exhaust airflow rates were varied from 200 CFM to 50 SCFM. Attempts were made to run all tests at the same 0.25, 0.50, 0.75 and 1.00 fixed ratios of exhaust to supply air; however, as seen in Figures 7 to 12, actual test condition varied slightly. Small variations were not a problem because the final results are a set of curve fits covering the entire testing range of flow ratios. The data sets generated during the evaluation yielded representative curve fit algorithms for unbalanced flow performance at three distinctive test conditions.

Figures 7 and 8 illustrate the EV 200 ERV performance parameters as measured during testing at ANSI/AHRI Standard 1060-2005 SA cooling point conditions (Table 1 and 2, Test Points 1 through 4) with Table 4 providing coefficients for the experimental data curve fits to the second-order polynomial equations. At nominal operating air-flow conditions, ERV total effectiveness was 0.538 with latent effectiveness recorded at 0.437 and sensible effectiveness at 0.704. Corresponding supply air total load reduction capacity was 1.763 kW, broken into 0.861 kW latent, and 0.902 kW sensible. Unbalancing airflows resulted in increased ERV effectiveness but reduced capacity. At the greatest unbalanced 1:4 ratio of exhaust to supply airflow conditions, total effectiveness increased to 0.977, latent to 0.791, and sensible effectiveness was recorded at 1.283. Higher than 1 sensible effectiveness readings are a result of the test loop recording Apparent Sensible Effectiveness that also includes the effect of motor heat gain, cross leakage gain, and casing gain. Increased effectiveness was accompanied by a reduction in ERV capacity, which was recorded at 0.817 kW total, 0.403 kW latent, and 0.414 kW sensible.

The same set of performance parameters were measured at the altered ANSI/AHRI Standard 1060-2005 SA heating point conditions (Table 1 and 2, Test Points 5–8) and are illustrated by Figures 9 and 10 with Table 5 providing coefficients for the experimental data curve fits to the second-order polynomial equations. With the colder supply air entering the unit, the impacts of external heat gain on tested unit sensible effectiveness was even more dramatic. At nominal operating air-flow conditions, ERV total effectiveness was 0.627, with latent recorded at 0.454 and sensible at 0.827. Corresponding supply air total load reduction capacity was 1.622 kW, 0.610 kW latent, and 1.012 kW sensible. Similar to the observations at the ANSI/AHRI Standard 1060-2005 SA cooling point conditions, unbalancing airflows resulted in increased ERV effectiveness and reduced capacity. At the greatest unbalanced 1:4 ratio of exhaust to supply airflow conditions, total effectiveness increased to 1.184, latent to 0.697, and sensible to 1.696. Corresponding total capacity was reduced to 0.733 kW, latent to 0.214 kW, and sensible to 0.519 kW.

Finally, Figures 11 and 12 show performance parameters measured during testing at high outdoor humidity conditions (Table 1 and 2 test points 9 through 12) with Table 6 providing coefficients for the experimental data curve fits to the second-order polynomial equations. At nominal operating air-flow conditions, ERV total effectiveness was 0.534 with latent recorded at 0.545 and sensible at 0. 34. Low sensible effectiveness is result of the small dry bulb temperature difference between supply and exhaust air. The corresponding supply air total load reduction capacity was 1.316 kW, 1.219 kW latent, and 0.097 kW sensible. At the greatest unbalanced 1:4 ratio of exhaust to supply airflow conditions, total effectiveness increased to 0.958, latent to

0.981, and sensible to 0.709. Corresponding total capacity was reduced to 0.572 kW, 0.518 kW latent, and 0.054 kW sensible.

Additional measurements of the pressure drop across the ERV as a function of supply and exhaust airflow rates were recorded for Tests 9 through 12. Figure 13 shows the correlation between exhaust air pressure and electric power consumption of the tested unit. The measured pressure drop of 0.484 inches of H_2O was recorded for both air streams at nominal operating conditions of balanced flow. At the greatest unbalanced flow ratio 1:4 ratio of exhaust to supply, exhaust air pressure drop was reduced to 0.162 inches of H_2O. Corresponding electric power consumption of the tested ERV ranged from 178.2 Watts at balanced flow conditions to 130.5 Watts at 1:4 ratio of exhaust to supply airflow.

Exhaust to Supply Airflow Ratio Impact on Apparent Effectiveness of EV200 Energy Recovery Ventilator

(Constant Supply Airflow 200 SCFM)

Figure 7. Performance of RenewAire ERV Model EV 200 operating in unbalanced mode at ANSI/AHRI Standard 1060-2005 SA cooling point conditions

Exhaust to Supply Airflow Ratio Impact on EV200 Energy Recovery Ventilator Supply Air Load Reduction

(Constant Supply Airflow 200 SCFM)
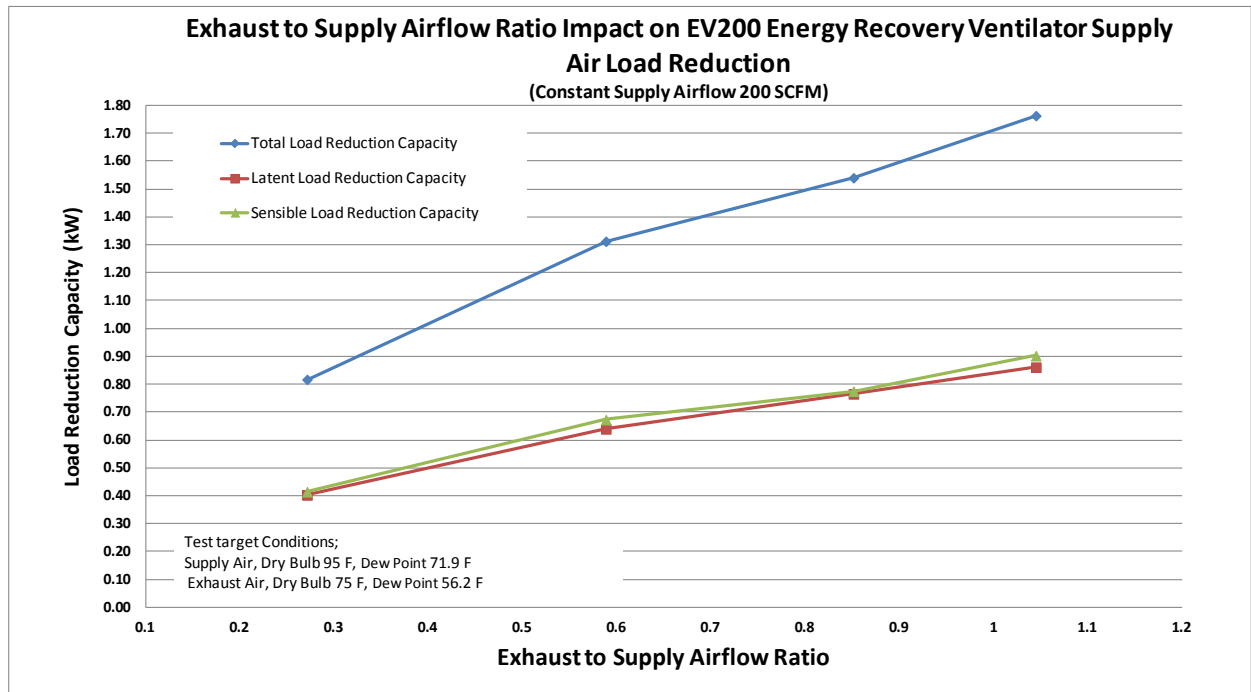
Figure 8. Supply air load reduction capacity of RenewAire ERV Model EV 200 operating in unbalanced mode at ANSI/AHRI Standard 1060-2005 SA cooling point conditions

Table 5. Parameter Curve Fit Coefficients and R² Values for the RenewAire ERV Model EV 200 Operating in Unbalanced Mode at ANSI/AHRI Standard 1060-2005 SA Cooling Point Conditions

Coeff.	TotEff	LatEff	SensEff	TotCap	LatCap	SensCap
	(-)	(-)	(-)	(kW)	(kW)	(kW)
a_0	1.274338	1.025932	1.686646	0.344414	0.164952	0.179462
a_1	-1.269774	-1.010321	-1.709054	1.920380	0.961840	0.958540
a_2	0.550553	0.437354	0.743341	-0.553905	-0.287355	-0.266550
R^2	0.991	0.983	0.997	0.995	0.998	0.989

$$Parameter = a_0 + a_1(EA/SA) + a_2(EA/SA)^2$$

where;

EA/SA = SCFM ratio of exhaust to supply airflow

Parameters;

TotEff = Total Effectiveness

LatEff = Latent Effectiveness

SensEff = Sensible Effectiveness

TotCap = Total Capacity
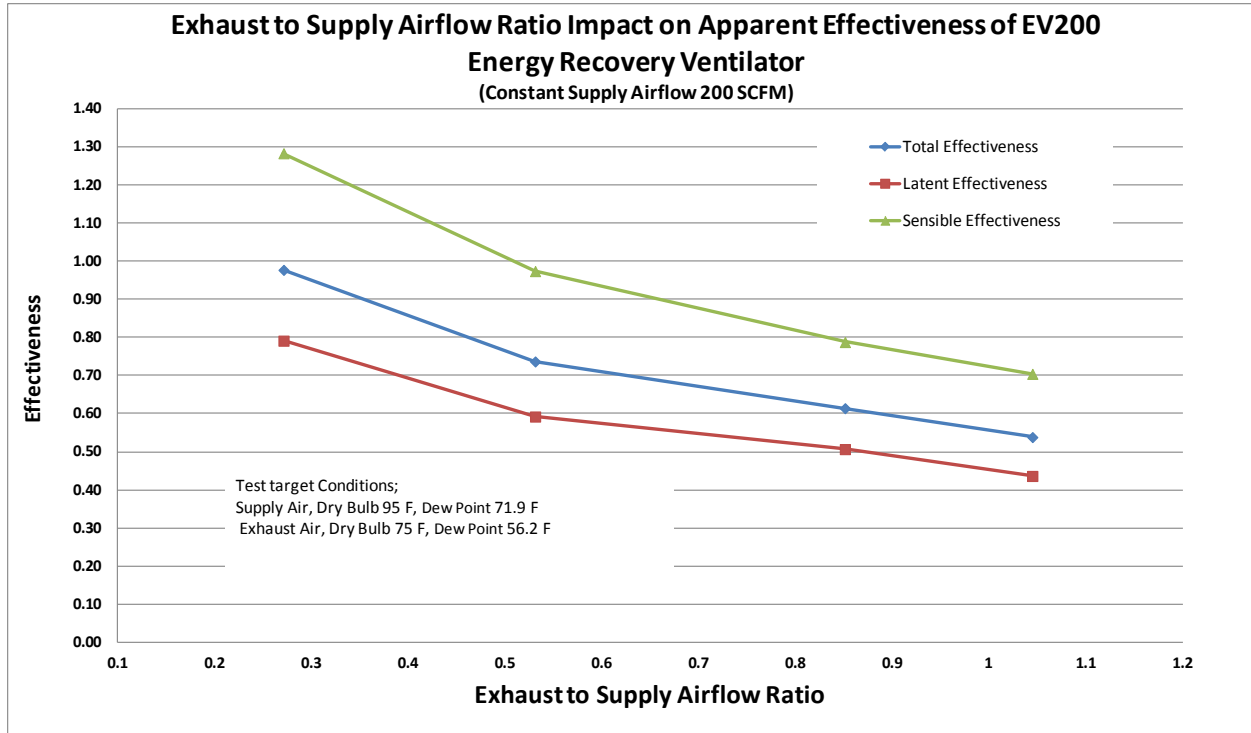
LatCap = Latent Capacity

SensCap = Sensible Capacity
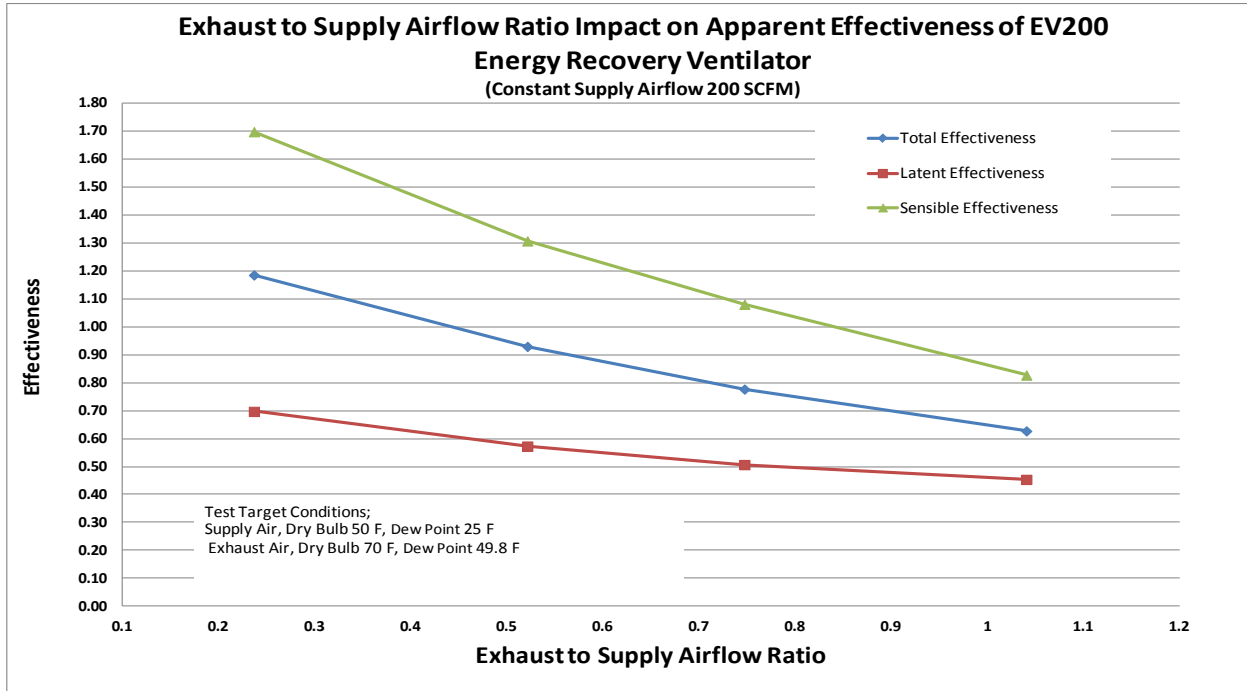
Figure 9. Performance of RenewAire ERV Model EV 200 operating in unbalanced mode at ANSI/AHRI Standard 1060-2005 SA modified heating point conditions
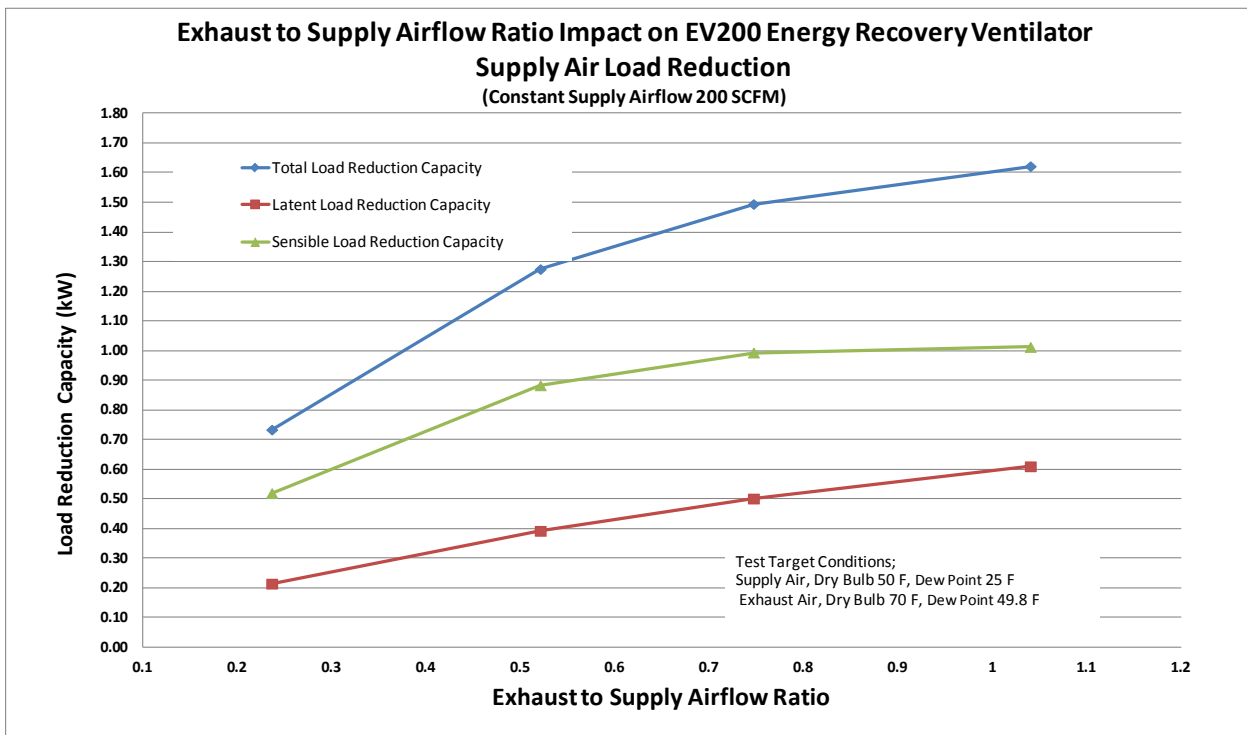
Figure 10. Supply air load reduction capacity of RenewAire ERV Model EV 200 operating in unbalanced mode at ANSI/AHRI Standard 1060-2005 SA modified heating point conditions

Table 6. Parameter Curve Fit Coefficients and R^2 Values for the RenewAire ERV model EV 200 Operating in Unbalanced Mode at ANSI/AHRI Standard 1060-2005 SA Modified Heating Point Conditions

Coeff.	TotEff	LatEff	SensEff	TotCap	LatCap	SensCap
	(-)	(-)	(-)	(kW)	(kW)	(kW)
a_0	1.440064	0.828731	2.069559	0.128469	0.037006	0.091463
a_1	-1.172791	-0.617778	-1.704541	2.910409	0.807615	2.102793
a_2	0.376714	0.247710	0.492364	-1.421744	-0.247649	-1.174095
R^2	1.000	1.000	1.000	0.999	1.000	0.997

Parameter = a_0 + a_1(EA/SA) + a_2(EA/SA)^2, EA/SA = SCFM ratio of exhaust to supply airflow
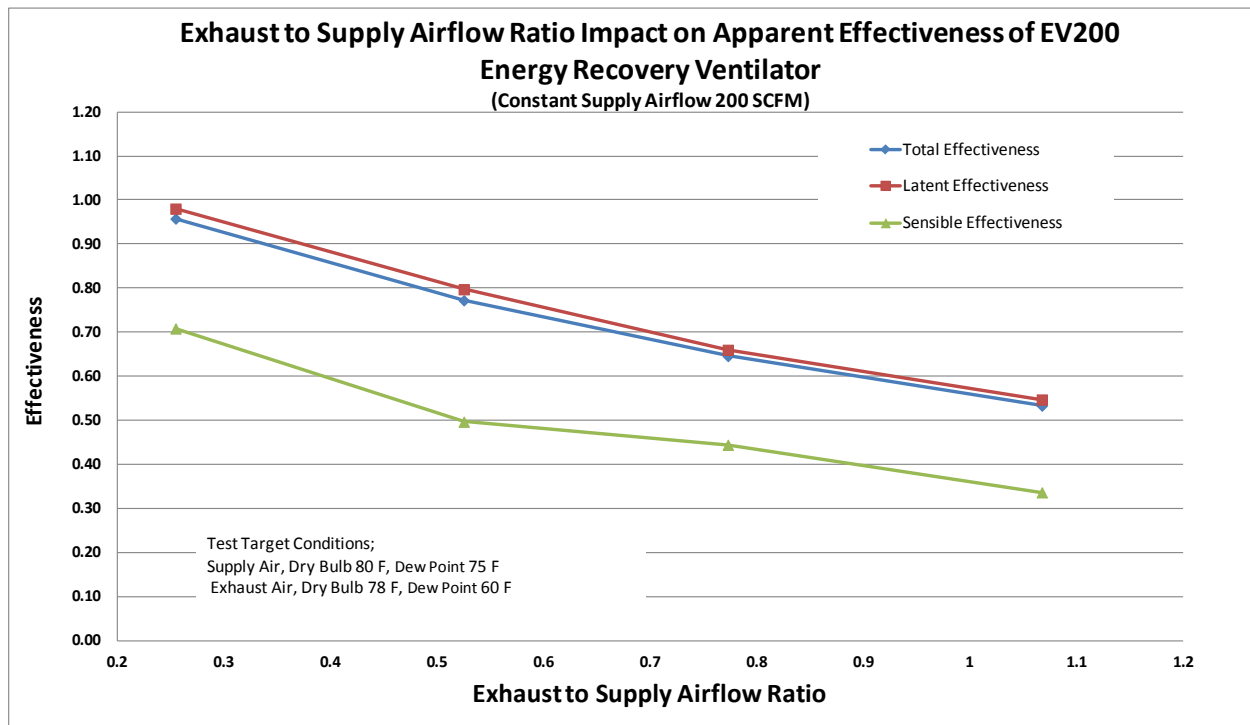
Figure 11. Performance of RenewAire ERV Model EV 200 operating in unbalanced mode at high outdoor humidity conditions
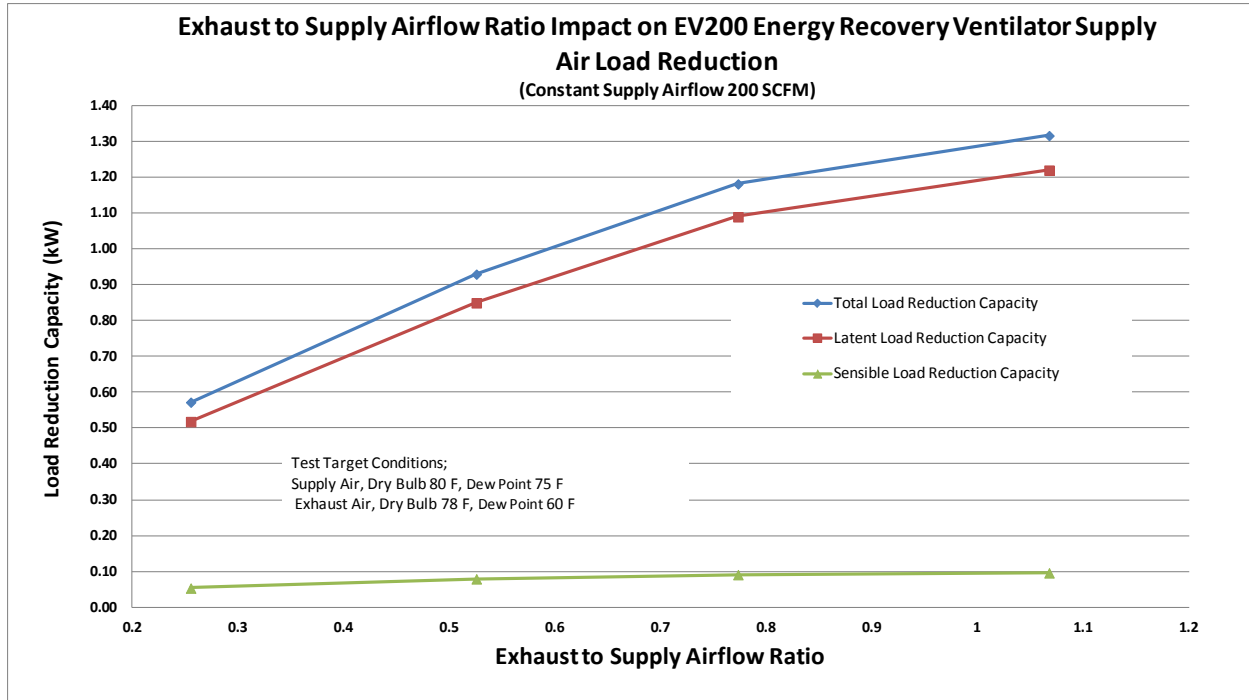
Figure 12. Supply air load reduction capacity of RenewAire ERV Model EV 200 operating in unbalanced mode at high outdoor humidity conditions

Table 7. Parameter Curve Fit Coefficients and R^2 Values for the RenewAire ERV Model EV 200 Operating in Unbalanced Mode at High Outdoor Humidity Conditions

Coeff.	TotEff	LatEff	SensEff	TotCap	LatCap	SensCap
	(-)	(-)	(-)	(kW)	(kW)	(kW)
a_0	1.168046	1.193350	0.912370	0.111153	0.089953	0.021200
a_1	-0.898362	-0.902133	-0.930681	2.006011	1.857357	0.148655
a_2	0.285260	0.277785	0.373935	-0.819702	-0.746357	-0.073345
R^2	1.000	1.000	0.975	0.999	0.999	0.999

Parameter = a_0 + a_1(EA/SA) + a_2(EA/SA)^2, EA/SA = SCFM ratio of exhaust to supply airflow
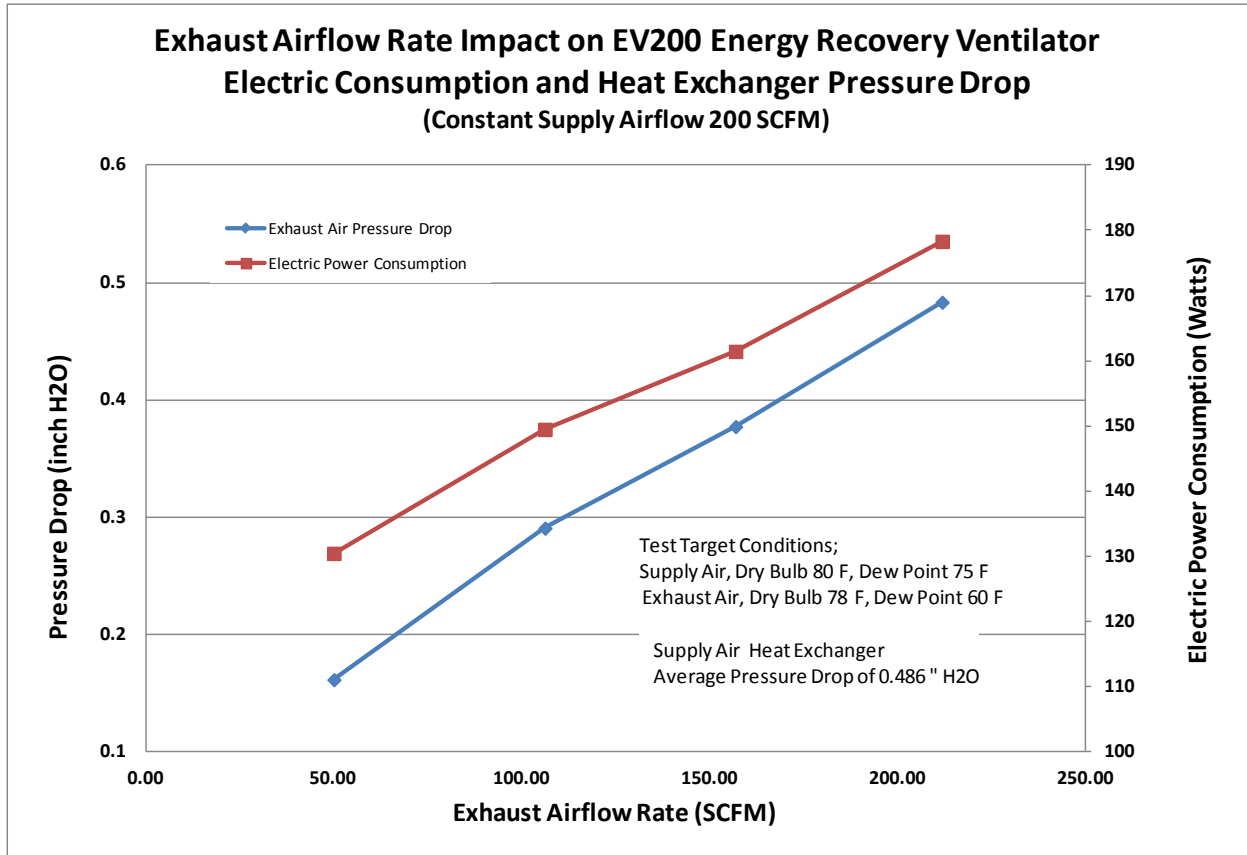
Figure 13. RenewAire ERV Model EV 200 electric consumption and heat exchanger pressure drop as function of exhaust air-flow rate

5 Findings and Recommendations

Following are the qualitative findings and recommendations based on the research questions addressed by this project.

Research Question: What are the sensible and latent effectiveness values of a membrane-based ERV over the full range of possible unbalanced operation (i.e., actively stepping down from 100% to 25% exhaust airflow while at 100% supply airflow)?

- The conducted tests show significant variation in ERV effectiveness operating at different levels of unbalanced airflows. Keeping supply airflow constant and lowering exhaust airflow increases effectiveness of both latent and sensible heat exchange.

- Under increasing unbalanced flow conditions, sensible load effectiveness of the tested ERV unit exceeded a value of 1 at two sets of testing conditions. This was a result of the temperature rise of the supply air as it passed through an ERV augmented by the effect of motor heat gain, cross leakage heat gain, and casing heat gain. Consequently, measured sensible effectiveness should be qualified as the so-called Apparent Sensible Effectiveness of the ERV unit (the term used in the CSA C439 standard for testing ERVs).

- Identifying measured sensible effectiveness as Apparent Sensible Effectiveness means that the unit-measured total effectiveness should be defined as Apparent Total Effectiveness as well.

- Because of the cross leakage between airstreams, calculation of the ERV effectiveness should be based on supply air outlet and exhaust air inlet airflows. Currently, ANSI/AHRI Standard 1060-2005 and EnergyPlus refer simply to "supply air" without specifying if it is the inlet or outlet airstream.

Research Question: What is the impact of ERV unbalancing on its capacity to condition supply air entering the building?

- The increased effectiveness at lower exhaust airflows is accompanied by reduced capacity for load removal from the supply air delivered to the conditioned space.

Research Question: How does unbalanced operation of the ERV affect its electric energy consumption?

- As the exhaust airflow is lowered, it is accompanied by directly proportional reductions in pressure drop and fan electrical consumption.

The following additional findings and recommendations were derived from the unbalanced flow testing of the RenewAire ERV model EV 200.

- The EnergyPlus software does not currently have the capability to model unbalanced flow ERV operation.

- The EnergyPlus software assumes the ERV sensible load effectiveness is proportional to the difference in the absolute humidity ratio of both streams. However, coincidental dry bulb temperature or the resulting relative humidity difference will have an additional influence not accounted for in the EnergyPlus model.

- Expanded tests of ERV performance with a test matrix covering a wider range of absolute and relative humidity ratio conditions would be needed to develop a set of equations to model ERV operation in balanced and unbalanced mode at a full range of typical indoor and outdoor conditions.

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Appendix A. Measured and Calculated Test Data and Performance Parameters

Detailed measured and collected test data and calculated performance parameters for the tested ERV equipment are listed in Tables A-1 through A-3.

Table A-1. Test Details of RenewAire ERV Model EV 200 Operating in Unbalanced Mode at ANSI/AHRI Standard 1060-2005 SA Cooling Point Conditions (Supply Air, Dry Bulb 95°F, Dew Point 71.9°F and Exhaust Air, Dry Bulb 75°F, Dew Point 56.2°F).

Parameter	Description	Units	Test # 1	Test # 2	Test # 3	Test # 4
TimeTU	Test Duration	minutes	31.8	61.7	24.0	20.5
PA	Ambient Pressure	Pa	93936	94799	94762	94161
WattIn	Power Consumption	Watt	172.9	162.8	149.6	132.8
SDBIn	Supply air IN dry bulb temperature	deg C	35.28	35.12	35.42	34.74
SDPIn	Supply air IN dew point temperature	deg C	21.78	21.65	21.93	21.89
SWIn	Supply air IN absolute humidity ratio	kg/kg	0.017687	0.017382	0.017704	0.017769
SVFIn	Supply air IN volumetric flow	SCFM	199.1	198.0	198.4	198.3
SDBOut	Supply air OUT dry bulb temperature	deg C	27.17	28.16	29.56	31.14
SDPOut	Supply air OUT dew point temperature	deg C	18.38	18.60	19.54	20.40
SWOut	Supply air OUT absolute humidity ratio	kg/kg	0.014324	0.014389	0.015280	0.016242
SVFOut	Supply air OUT volumetric flow	SCFM	185.9	185.7	191.8	191.9
EDBIn	Exhaust air IN dry bulb temperature	deg C	24.31	24.27	24.14	23.93
EDPIn	Exhaust air IN dew point temperature	deg C	13.47	13.26	13.08	13.43
EWIn	Exhaust air IN absolute humidity ratio	kg/kg	0.010344	0.010130	0.010033	0.010337
EVFIn	Exhaust air IN volumetric flow	SCFM	194.2	150.5	101.8	49.5
EDBOut	Exhaust air OUT dry bulb temperature	deg C	32.87	33.37	34.33	34.60
EDPOut	Exhaust air OUT dew point temperature	deg C	17.91	18.04	19.16	20.52
EWOut	Exhaust air OUT absolute humidity ratio	kg/kg	0.013891	0.013881	0.014921	0.016354
EVFOut	Exhaust air OUT volumetric flow	SCFM	209.0	164.1	109.2	56.4
MassFlowBal	Mass Balance	(-)	0.005%	-0.008%	0.006%	-0.001%
SensEnerBal	Heat Balance Sensible	(-)	0.694%	0.379%	-0.657%	-1.351%
LatEnerBal	Heat Balance Latent	(-)	0.349%	-0.602%	0.402%	-0.049%
TotEff	Total Effectiveness	(-)	0.538	0.614	0.737	0.977
LatEff	Latent Effectiveness	(-)	0.437	0.507	0.592	0.791
SensEff	Sensible Effectiveness	(-)	0.704	0.788	0.974	1.283
TotCap	Supply Air Total Load Reduction Capacity	kW	1.763	1.540	1.312	0.817
LatCap	Supply Air Latant Load Reduction Capacity	kW	0.861	0.765	0.639	0.403
SensCap	Supply Air Sensible Load Reduction Capacity	kW	0.902	0.775	0.673	0.414

Very high accuracy of mass flow balance listed in Table A-1 is result of using NREL-approved methodology of calculating Exhaust Air Flow (EVFOut) from measured volumetric flow rates of three air remaining flow streams (SVFIn, SVFOut, EVFIn)

Table A-2. Test Details of RenewAire ERV model EV 200 operating in unbalanced mode at ANSI/AHRI Standard 1060-2005 SA modified heating point conditions (Supply Air, Dry Bulb 50°F, Dew Point 25°F and Exhaust Air, Dry Bulb 70°F, Dew Point 49.8°F)

Parameter	Description	Units	Test # 5	Test # 6	Test # 7	Test # 8
TimeTU	Test Duration	minutes	33.5	32.0	38.8	41.3
PA	Ambient Pressure	Pa	95040	95110	96370	96340
WattIn	Power Consumption	Watt	174.9	164.4	151.1	134.6
SDBIn	Supply air IN dry bulb temperature	deg C	10.60	10.09	9.56	9.97
SDPIn	Supply air IN dew point temperature	deg C	-3.53	-3.41	-3.22	-2.96
SWIn	Supply air IN absolute humidity ratio	kg/kg	0.003087	0.003113	0.003118	0.003179
SVFIn	Supply air IN volumetric flow	SCFM	197.7	203.0	197.2	198.0
SDBOut	Supply air OUT dry bulb temperature	deg C	19.81	18.67	17.38	14.54
SDPOut	Supply air OUT dew point temperature	deg C	4.08	2.76	1.91	-0.04
SWOut	Supply air OUT absolute humidity ratio	kg/kg	0.005400	0.004910	0.004559	0.003958
SVFOut	Supply air OUT volumetric flow	SCFM	189.7	200.5	195.7	197.2
EDBIn	Exhaust air IN dry bulb temperature	deg C	21.33	20.76	21.10	21.41
EDPIn	Exhaust air IN dew point temperature	deg C	9.81	9.56	9.89	9.81
EWIn	Exhaust air IN absolute humidity ratio	kg/kg	0.007996	0.007874	0.007960	0.007924
EVFIn	Exhaust air IN volumetric flow	SCFM	197.5	149.8	102.0	46.7
EDBOut	Exhaust air OUT dry bulb temperature	deg C	14.00	12.89	11.70	11.20
EDPOut	Exhaust air OUT dew point temperature	deg C	4.80	3.96	3.17	0.97
EWOut	Exhaust air OUT absolute humidity ratio	kg/kg	0.005679	0.005348	0.004990	0.004256
EVFOut	Exhaust air OUT volumetric flow	SCFM	206.2	152.8	103.8	47.5
MassFlowBal	Mass Balance	(-)	0.001%	-0.003%	-0.006%	-0.006%
SensEnerBal	Heat Balance Sensible	(-)	2.364%	4.542%	5.764%	5.470%
LatEnerBal	Heat Balance Latent	(-)	0.197%	-0.575%	-1.184%	-1.616%
TotEff	Total Effectiveness	(-)	0.627	0.776	0.929	1.184
LatEff	Latent Effectiveness	(-)	0.454	0.507	0.573	0.697
SensEff	Sensible Effectiveness	(-)	0.827	1.080	1.306	1.696
TotCap	Supply Air Total Load Reduction Capacity	kW	1.622	1.494	1.275	0.733
LatCap	Supply Air Latant Load Reduction Capacity	kW	0.610	0.501	0.392	0.214
SensCap	Supply Air Sensible Load Reduction Capacity	kW	1.012	0.993	0.883	0.519

Very high accuracy of mass flow balance listed in Table A-2 is result of using NREL-approved methodology of calculating Exhaust Air Flow (EVFOut) from measured volumetric flow rates of three air remaining flow streams (SVFIn, SVFOut, EVFIn)

Table A-3. Test Details of RenewAire ERV model EV 200 operating in unbalanced mode at high outdoor humidity conditions (Supply Air, Dry Bulb 80ºF, Dew Point 75ºF and Exhaust Air, Dry Bulb 78ºF, Dew Point 60ºF)

Parameter	Description	Units	Test # 9	Test # 10	Test # 11	Test # 12
TimeTU	Test Duration	minutes	35.4	57.2	59.5	62.8
PA	Ambient Pressure	Pa	94490	94307	94591	94536
WattIn	Power Consumption	Watt	178.3	161.5	149.5	130.5
SDBIn	Supply air IN dry bulb temperature	deg C	26.92	27.17	27.13	27.17
SDPIn	Supply air IN dew point temperature	deg C	23.71	23.62	23.47	23.46
SWIn	Supply air IN absolute humidity ratio	kg/kg	0.019835	0.019768	0.019540	0.019527
SVFIn	Supply air IN volumetric flow	SCFM	197.4	199.5	197.5	195.9
SDBOut	Supply air OUT dry bulb temperature	deg C	26.40	26.68	26.67	26.85
SDPOut	Supply air OUT dew point temperature	deg C	19.28	19.87	20.58	21.74
SWOut	Supply air OUT absolute humidity ratio	kg/kg	0.015073	0.015688	0.016362	0.017605
SVFOut	Supply air OUT volumetric flow	SCFM	186.2	194.3	194.6	196.5
EDBIn	Exhaust air IN dry bulb temperature	deg C	25.48	25.75	25.39	25.40
EDPIn	Exhaust air IN dew point temperature	deg C	15.45	15.51	15.76	15.62
EWIn	Exhaust air IN absolute humidity ratio	kg/kg	0.011714	0.011807	0.011990	0.011886
EVFIn	Exhaust air IN volumetric flow	SCFM	198.7	150.2	102.2	50.1
EDBOut	Exhaust air OUT dry bulb temperature	deg C	27.06	27.50	27.40	27.79
EDPOut	Exhaust air OUT dew point temperature	deg C	20.33	21.14	21.83	23.09
EWOut	Exhaust air OUT absolute humidity ratio	kg/kg	0.016122	0.016995	0.017697	0.019130
EVFOut	Exhaust air OUT volumetric flow	SCFM	211.8	156.9	106.2	50.1
MassFlowBal	Mass Balance	(-)	-0.011%	-0.006%	-0.012%	-0.005%
SensEnerBal	Heat Balance Sensible	(-)	1.219%	1.090%	0.849%	0.495%
LatEnerBal	Heat Balace Latent	(-)	-0.738%	-0.401%	-0.732%	-0.279%
TotEff	Total Effectiveness	(-)	0.534	0.646	0.773	0.958
LatEff	Latent Effectiveness	(-)	0.547	0.660	0.798	0.981
SensEff	Sensible Effectiveness	(-)	0.337	0.445	0.497	0.709
TotCap	Supply Air Total Load Reduction Capacity	kW	1.316	1.181	0.929	0.572
LatCap	Supply Air Latant Load Reduction Capacity	kW	1.219	1.089	0.850	0.518
SensCap	Supply Air Sensible Load Reduction Capacity	kW	0.097	0.092	0.080	0.054

Very high accuracy of mass flow balance listed in Table A-3 is result of using NREL-approved methodology of calculating Exhaust Air Flow (EVFOut) from measured volumetric flow rates of three air remaining flow streams (SVFIn, SVFOut, EVFIn)