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Residential dual core energy recovery ventilation system for ventilation of northern housing

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Abstract. Heat/energy recovery ventilation systems are types of HVAC that can reduce energy consumption and improve the ventilation rate of housing in cold climates. Their performance achieved to date has been inadequate due to equipment failures (freezing of cores, noise, etc.). Freezing of cores is common in extremely cold climates. Single core HRV/ERV units are usually equipped with defrost strategies such as recirculation of exhaust stale air across the heat exchanger and back into the supply air to the house. These defrost strategies can undermine ventilation standards (ventilation rate requirement not being met during recirculation). This paper presents a rigorous investigation on the performance of dual core energy recovery system that provided a continuous ventilation rate at outdoor temperatures below -10°C without frost protection. The dual core ERV had higher apparent sensible effectiveness (up to 12% more) and apparent total effectiveness (up to 9% more) than a conventional single core ERV. It showed no sign of frost problems after four weeks of winter testing, continuously provided outdoor air without stopping to defrost, unlike the conventional single core ERV which required up to 7.5 hours defrosting per day, and also provided a higher supply air temperature (up to 3°C) to indoors with a total whole-house energy saving of 4.7%.

1. Introduction

The extremes of the Arctic climate pose severe challenges on housing ventilation and heating systems. In the Arctic and northern regions of Canada, the average temperature during winter is -25°C or below, and many northern homes are heated to above 25°C resulting in significant loads on systems (Zaloum, 2010). As a part of the overall effort to reduce space heating requirements, homes are built air tight to reduce infiltration or exfiltration heat losses. However, airtight homes require energy efficient, effective and resilient ventilation systems to maintain acceptable indoor air quality and comfort, and to protect the building envelope from moisture damage. A balanced mechanical ventilation system with heat or energy recovery is an ideal way to meet both National Building Code [1] and the ventilation requirements of standards [2, 3]. Heat recovery ventilation (HRV) and energy recovery ventilation (ERV) are well-known and effective methods to improve energy and ventilation efficiency of residential heating, ventilating and air conditioning (HVAC) systems when designing energy efficient homes, because they allow adequate outdoor ventilation air without excessive energy consumption. The performance of the conventional single core HRV/ERV units achieved to date has been inadequate due to equipment failures and conventional problems created by the formation of frost in heat exchangers. Freezing of cores can cause partial or full blockage of air flow passages, increased pressure drop through the heat exchanger or decreased airflow rate, increased electrical power consumption for the fans, decreased heat transfer rate between the two airstreams, and cold draughts within the space due to low supply air temperatures [4]. Conventional single core HRV/ERV units are usually equipped with frost protection systems such as pre-heating of outdoor air or recirculating of return air across the heat exchanger and back into the supply air to the house. These defrost strategies can undermine ventilation standards (ventilation rate requirement not being met) and the energy saving of the HRV or ERV unit. Surveys conducted in Canada's North found that at present, there are

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no HRVs/ERVs specifically designed, manufactured and certified to meet rigorous requirements for operation in the North [5]. This paper presents some results from a project employing an innovative dual core design heat/energy recovery system and its applicability for housing in the Arctic. One alternative technology that can overcome problems faced by conventional single core HRV/ERV units installed in extreme cold climates is a dual core ERV unit designed to address frost protection concerns and provide continuous ventilation.

2. Method

The rigorous methodology used in this investigation included the following evaluation steps:

- Laboratory evaluation using two climatic chambers to simulate indoor and outdoor conditions identified by a certification standards and those identified in the North,
- Side-by-side testing using twin research houses to compare whole-building performance between a reference house equipped with a single core ERV and a test house equipped with a dual core energy recovery unit, and
- Extended performance and resiliency testing in a real northern environment, with representative climate and occupied loads.

However, this paper presents some results from the side-by-side testing using the CCHT twin houses.

2.1. Description of the dual core ERV

A dual core ERV unit comes equipped with a regenerative cyclic dual core heat exchanger, based on the cyclic storage and release of heat in the corrugated plates alternately exposed to exhaust and intake air. It includes a supply and exhaust fan and two plate heat exchangers, which act as heat accumulators. In between the cores is a patented damper section which changes over every 60 seconds to periodically direct warm air through one of the two cores while outside air gains heat from the heated plates in the other core. In front of each fan is a filter section to filter the air. The schematic of the dual core unit is presented in Figure 1, where OA is the outdoor air, EA is the exhaust air to outdoor, RA is the return air from indoor and SA is the supply air to indoor. The description of the two sequences of the unit is as follow. During *Sequence 1*, exhaust air charges Core B with heat from exhausted warm air from indoors and Core A discharges heat to the supply air: During *Sequence 2* the exhaust air charges Core A with heat from exhausted warm air from indoors and Core B discharges heat to the supply air. The damper is controlled by two internal thermostats (thermostat 1 in the supply air is set to 15°C and thermostat 2 in the exhaust air is set to 20°C) to ensure that comfortable air delivery temperatures are achieved under all conditions. When the exhaust air temperature is below 20°C, the unit runs in energy recovery mode (cycling every 60 seconds). When the exhaust air temperature is above 20°C and the supply air temperature is higher than 15°C, the unit runs in free cooling mode (cycling every 3 hours). Finally, when the exhaust air temperature is above 20°C and the supply air temperature is below 15°C, the unit runs in energy recovery mode until the supply air temperature exceeds 15°C, at which point it will revert to free cooling mode.

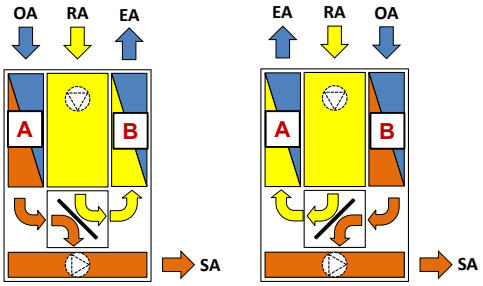

Figure 1. Principle of function – sequence 1 (left) and sequence 2 (right)

2.2. Side-by-side testing

The Canadian Centre for Housing Technology's (CCHT) twin research houses shown in Figure 2 (left) were used for the comparative side-by-side testing between a dual core ERV (installed in the test house) and a conventional single core ERV (installed in the reference house). These houses are typical

2-storey wood-frame houses with their characteristics presented in Figure 2 (right). The twin-house research facility features a "simulated occupancy system". The simulated occupancy system, utilizes home automation technology to simulate human activity by operating major appliances (stove, dishwashers, washer and dryer), lights, water valves, fans, and other sources simulating typical heat gains. The schedule is typical of activities that would take place in a home with a family comprised of two adults and two children. Electrical and water consumption are typical for a family of four. The heat given off by humans is simulated by two 60 W (2 adults) and two 40 W (2 children) incandescent bulbs at various locations in the house. The CCHT research houses are equipped with a data acquisition system (DAS) consisting of over 250 sensors and 23 metering devices (gas, water and electrical). A computer reads the sensors every 5 minutes and provides hourly averages. Meter data and a few other measurements are recorded on a 5 minute-basis. The DAS captures a clear history of the house performance in terms of temperature, humidity and energy consumption.

Feature	Details
Construction Standard	R-2000
Liveable Area	210 m^2 (2260 ft^2), 2 storeys
Insulation	Attic: RSI 8.6, Walls: RSI 3.5, Rim joists: RSI 3.5
Basement	Poured concrete, full basement. Floor: Concrete slab, no insulation. Walls: RSI 3.5 in a framed wall. No vapour barrier.
Garage	Two-car, recessed into the floor plan; isolated control room in the garage
Exposed floor over the garage	RSI 4.4 with heated/cooled plenum air space between insulation and sub-floor.
Windows	Low-e coated, argon filled windows Area: 35.0 m^2 (377 ft^2) total, 16.2 m^2 (174 ft^2) South Facing
Air Barrier System	Exterior, taped fiberboard sheathing with laminated weather resistant barrier. Taped penetrations, including windows.
Airtightness	1.5 air changes per hour @ 50 Pa (1.0 lb/ft^2)
Furnishing	Unfurnished

Figure 2. CCHT twin houses (left) and their characteristics (right)

The side-by-side testing involved first benchmarking the houses for set operating conditions and simulated occupancy, using existing high efficiency single core ERVs originally installed in each house. The test house was modified by installing the dual core ERV unit in the basement and making no other modifications to the house, then programing the dual core unit to match the single core ERV supply and exhaust airflows in the reference house. Finally, whole-house performance was monitored for four weeks during the 2019 heating season.

2.3. Performance evaluation

The performance of the innovative dual core ERV unit was primarily determined by its apparent sensible effectiveness (ASE) and apparent total effectiveness (ATE) as described in ASHRAE testing standard [6] and Canadian testing standard [7], airflow characteristics, supply air temperature, frosting occurrence and whole-house energy consumption. The measured temperatures and relative humidities across the tested unit were used to calculate the ASEs and ATEs. The ASE and ATE were calculated using Equation 1.

$$\varepsilon = \frac{m_s(X_{SI} - X_{SO})}{m_{min}(X_{SI} - X_{EI})} \qquad (1)$$

where, ε is the sensible, latent, or total heat effectiveness. X is either the dry-bulb temperature, T, humidity ratio, w, or total enthalpy, h, respectively, at the supply inlet and outlet and at the exhaust inlet of the unit. m_s *is the* mass flow rate of the supply and m_{min} *is the* minimum value of either mass flow rate of the supply or mass flow arte of the exhaust.

3. Results and discussion

This section compares the operation of the two houses, the Reference House incorporating a single core ERV and the Test House incorporating a dual core ERV in terms of ventilation rate (airflows), sensible and total efficiencies of the ERV units, supply air temperature from the ERV units, and total energy consumption for heating and ventilating both houses.

3.1. Ventilation

The typical daily single ERV and dual core ERV supply and exhaust airflows are presented in Figure 3

for a cold day with an outdoor temperature below -10°C (January 17th 2019). The plot of the single core ERV airflows excluded the defrost cycle as shown on the left plot of Figure 3. Both single and dual core ERVs presented balanced supply and exhaust flows. The dual core ERV showed no sign of frost problems and continued to provide outdoor air throughout a cold testing day (outdoor temperature ranging between -20.1°C and -11.8°C) without stopping to defrost, unlike the single core ERV that had to spend hours defrosting as shown in the plot on the left side of Figure 3.

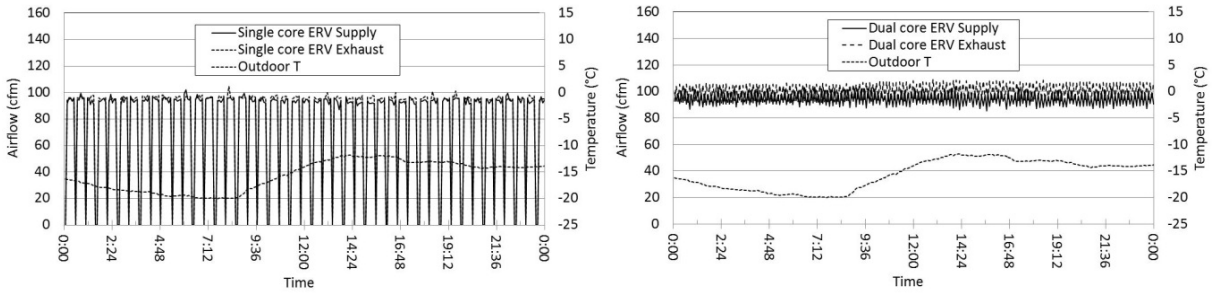

Figure 3. Measured airflows from side-by-side testing, Reference House (left) and Test House (right)

The single core ERV uses a defrosting method presented in Table 1. The amount of time the single core ERV spent in defrost mode ("defrost time") per day during the winter test period is presented in Figure 4 along with the minimum and mean outdoor temperatures. The duration of the de-icing cycle is strongly dependent on outdoor temperature. The single core ERV spent between 0 and 7.5 hours per day defrosting, during which time it did not provide fresh air to the reference house. Due to its design, the dual core ERV did not require defrosting, and provided fresh air continuously throughout the winter test period. The frequent defrost cycles of the single core ERV led to a reduced volume of outdoor air being delivered to the reference house, leading to under ventilation of the reference house (compared to the test house), and it not meeting the ventilation requirement. This is a common situation for single core HRV/ERV units installed in extremely cold climates.

Table 1. Defrosting method

Outside Temperature [°C]	Defrost Cycle Defrost [min] / Operating [min]
Warmer than -10	No Defrost
-10 to -27	7 / 25
-27 and less	10 / 22

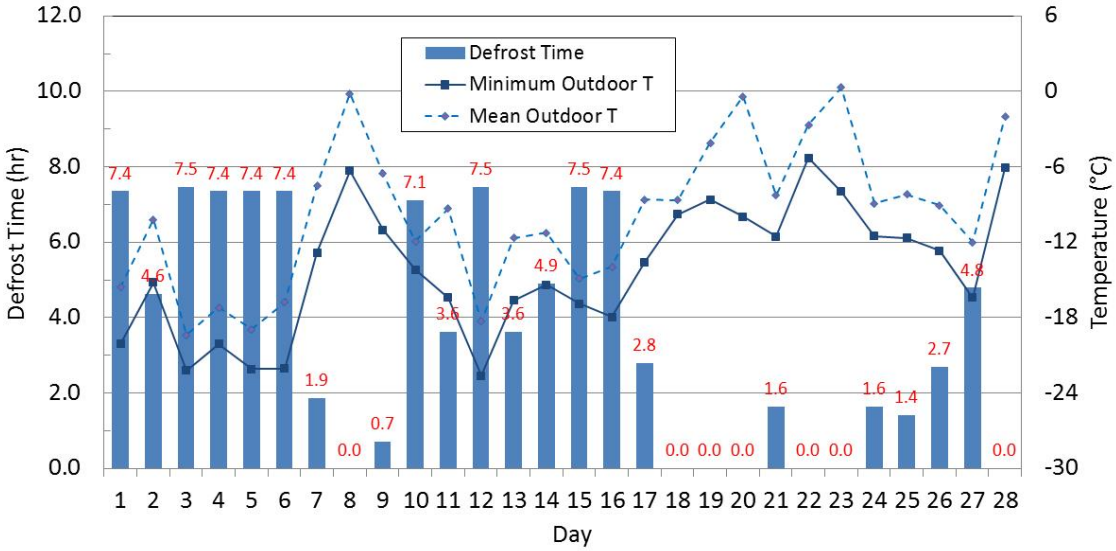

Figure 4. Daily single core ERV defrost time during winter 2019 testing

3.2. Effectiveness

The calculated ASE and ATE of a single core ERV and dual core ERV using data obtained from the side-by-side testing in the CCHT twin houses are presented in Figure 5 and Figure 6. The calculated ASE of the dual core ERV (installed in the test house) had a mean value of 85.1% and ranged from 63.2% to 99.4%. The single core ERV (installed in the reference house) had a mean value of ASE of 73.2% during the same testing period of four weeks and ranged from 62.3% to 94.2%, a mean difference over reference house of 12 percentage points. The ATE, which takes into account the latent heat of the single core ERV, varied between 58.4% and 91.4%, with a mean value of 69.9%. The dual core ERV unit had an ATE between 64.16% and 98.9%, with a mean value of 79.1%, a mean difference over the reference house of 9 percentage points. These results show clearly that the dual core ERV unit over perform the conventional single core ERV in terms of sensible and totale efficiencies.

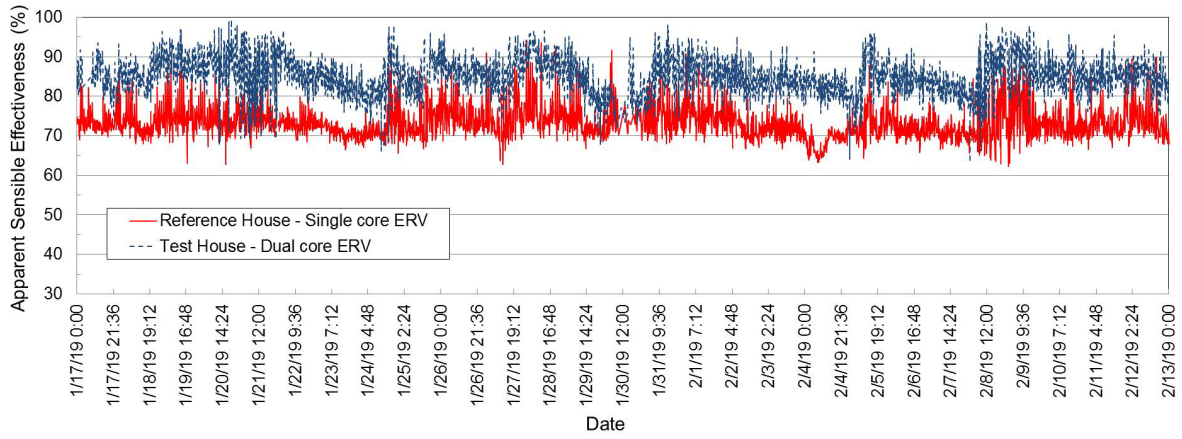

Figure 5. Calculated apparent sensible efficiencies

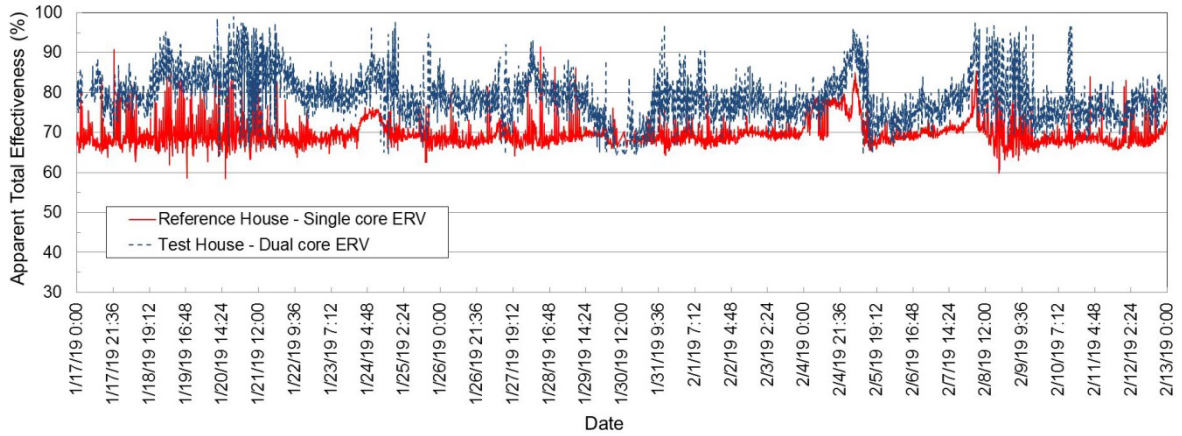

Figure 6. Calculated apparent total efficiencies

3.3. Supply air temperature

The temperature of the supply air from the single and dual core units to indoors (to return air plenum upstream of the furnace) measured during the side-by-side testing (January 17 to February 12, 2019) are presented in Figure 7 with the measured outdoor temperature. The supply outlet air temperature from the single core ERV in reference house varied between 7.5°C and 18.8°C and the test period mean value was 13.5°C. The supply outlet air temperature from the dual core ERV in test house varied between 9.9°C and 19.8°C and the mean value over the same testing period was 16.1°C. The mean temperature of the supplied air to the house was higher by 2.6°C from the dual core ERV than the single ERV. This was due to the much higher ASE of the dual core unit (higher than 80%) from regenerative cyclic dual cores. The supply air to the test house required less tempering by the furnace

to meet the thermostat set point of 22°C, which means that a dual core unit provided more pre-heating than a single core ERV and would lead to additional energy savings.

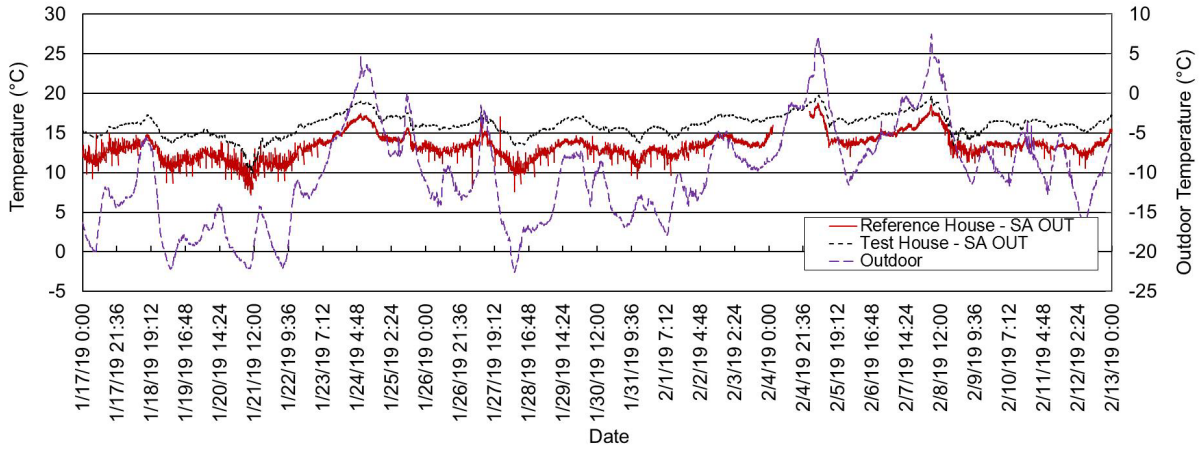

Figure 7. Measured supply air temperature from side-by-side testing

3.4. Energy

Changes in whole-house energy performance due to the innovation were addressed through comparison of the test house performance (with dual core ERV) to that of the reference house (with single core ERV). The recorded whole-house energy consumption of both reference house and test house included; heating energy consumption (furnace natural gas consumption), furnace fan electrical consumption, single core ERV fan electrical consumption and dual core ERV fan electrical consumption. The expected test house energy consumption in benchmark configuration (i.e. operating the benchmark ERV equipment, both houses with single core ERV) was first calculated, and from this the overall energy savings when the dual core ERV system was operating in the test house was calculated. Savings were calculated by subtracting the measured test house (with dual core ERV0 experiment consumption from the calculated test house (with single core ERV) benchmark consumption. The average energy saving when operating the dual core ERV compared to the benchmark ERV over the period of the study was 4.7%.

4. Conclusion

In comparison with conventional single core ERV, the dual core ERV designed with two parallel regenerative heat exchangers and a controlled cycling damper had higher ASE and ATE from side-by-side testing than the single core ERV. It was more frost-tolerant, showing no signs of frost problems, and was capable of withstanding an outdoor temperature down to -23°C without degrading its thermal performance, and provided a continuous supply of outdoor air without stopping to defrost, unlike the conventional single core ERV which spent many hours defrosting during cold days of the side-by-side testing. The dual core technology was capable of providing air at the supply outlet at a temperature 2.6°C higher than the air temperature supplied by a single core ERV. Its incorporation into the test house showed a saving in heating and ventilation energy consumption of approximately 4.7% (24.6 MJ/day). The project demonstrated that a dual core ERV is a viable solution for northern housing.

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