Long-term performance and resiliency testing of a dual core energy recovery ventilation system for the Arctic

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ABSTRACT

The Arctic environment is challenging for housing ventilation and heating systems. Energy consumption and demand for space heating for northern remote community residential buildings are very high. Airtight built northern homes require energy efficient and effective ventilation systems to maintain acceptable indoor air quality and comfort, and to protect the building envelope from moisture damage. Conventional single core heat/energy recovery ventilation systems are a mature and proven technology for modern and energy-efficient Canadian homes; but underperform and are plagued with problems when operating in high-arctic locations north of 60°. Their performance achieved to date has been inadequate due to equipment failures (freezing of cores, etc.) and their defrost strategies can undermine ventilation rate requirement and the energy saving. Inadequate ventilation in northern communities contribute to poor indoor air quality, and this contribute to increased cases of serious health issues; tuberculosis and asthma, specifically asthma infections among young Inuit children. To overcome these issues, a novel dual core energy recovery system designed with two heat exchangers could address frost protection by periodically directing warm air through one core of the two cores while outside air gains heat from the other. By employing a cycling heat exchanger, frost doesn't have a chance to form, and one heat exchanger is always delivering conditioned air to the space. This paper presents results from a repeated side-by-side winter testing using NRC's twin research houses comparing whole house performance of a reference house equipped with a single core ERV with a test house equipped with a dual core energy recovery unit, and some results from the long-term monitoring of the technology deployed in a triplex located in Canada's Arctic. The side-by-side testing was undertaken in the NRC twin-houses research facility of the Canadian Centre for Housing Technology (CCHT) over four weeks in winter 2019. In comparison with a conventional single core ERV, the dual core energy recovery system had much higher apparent sensible effectiveness, a difference of 12 percentage points, and had much higher apparent total effectiveness, a difference of 9 percentage points. The dual core design showed no sign of frost problems after 4 weeks of testing and continued to provide outdoor air throughout winter days without stopping to defrost, unlike the conventional single core ERV which had to spend up to 7.5 hours defrosting per day. It also provided a higher supply air temperature (up to 3°C) to indoor and the house with dual core ERV had a whole-house heating and ventilation energy saving of 5% over the winter testing period. The long-term performance testing was undertaken in a mechanical room of a triplex on the Canadian High Arctic Research Station (CHARS) in Cambridge Bay (Nunavut) to assess the resiliency and durability of the technology in harsh cold climate. The monitoring period included two heating seasons 2017-18 and 2018-19 and showed that the dual core technology was very frost-tolerant and capable of withstanding temperature below -40°C for long periods without deteriorating its thermal and ventilation performances, and providing constant and continuous supply of outdoor air. The proven performance and resiliency to harsh Arctic operating conditions demonstrates that the dual core design ERV is a solution to ventilation of northern housing, in providing continuous ventilation that will improve indoor air quality and health in Northern communities.

KEYWORDS

Residential, Ventilation, ERV, Dual core, Arctic

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 (NBCC, 2015) and the ventilation requirements of standards (ANSI/ASHRAE 62.2, 2016, CAN/CSA-F326-M91, 2013). 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 [Rafati et al., 2014). 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 no HRVs/ERVs specifically designed, manufactured and certified to meet rigorous requirements for operation in the North [CMHC, 2016). This paper presents some results from a project employing an innovative dual core design 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 SINGLE CORE HEAT OR ENERGY RECOVERY VENTILATORS

The exhaust air heat loss is a considerable part of the total heat loss in cold climates. Since typical ventilation systems introduce unconditioned outdoor air and exhaust conditioned indoor air, there is potential for energy savings by incorporating heat transfer between the two airstreams. This could be achieved by installing a heat or energy recovery ventilator. The core of a conventional HRV or ERV is constructed of a series of parallel plates that separate the exhaust and outdoor air streams. These plates are typically fabricated of metal or plastic. They simultaneously supplies and exhausts equal quantities of air to and from a house while transferring heat or energy between the two air streams. The heat or energy is transferred from exhaust to outdoor air stream during the heating season. The heat exchange process is reversed during cooling season. In cold winter conditions, the condensation inside the core can freeze and block the exhaust air stream. HRVs or ERVs are designed to protect against freezing and clear the core of ice going automatically into defrost mode. This is typically accomplished by a damper that closes of the outdoor air supply and allows warm indoor air into the HRV to heat the core and melt any ice on the exhaust side. Frost control strategies for conventional single core HRV/ERV are presented in Table 1 (Rafati et al., 2014). When operating in defrost mode, there is a temporary discontinuation in the indoor-outdoor air exchange. Another common method of defrost is to use a pre-heater, which is more applicable in colder climates where more constant defrost is required. Pre-heater increase energy costs and reduces the heat recovery efficiency of the HRV or ERV.

Table 1: Frost control strategies for HRVs/ERVs

Technique	Control Parameter	Capital Cost	Operating Cost	IAQ	Pros	Cons
Preheating the outdoor air	Temperature	↔	↑	↑	Simple, used as frost prevention	Not economical in cold climates
Reducing or closing the supply air	Flow rate	↔	↔	↓	Simple	Increases infiltration
Recirculating warm exhaust air	Flow rate	↔	↔	↓	Simple, high flow rate enhances the melting process	No supply of outdoor air
Bypassing the supply air partially or fully	Flow rate	↔	↑	↔	Simple	Reduced energy recovery

In North America, residential HRVs and ERVs are tested and rated using a standard test procedure that is described in the certification standard for heat/energy recovery ventilators (CSA-C439-09, 2015). The certification standard identifies a standard indoor condition of 22°C, 40% RH and an outdoor (supply) temperature of 0°C. The standard also provides a test procedure for an optional low temperature performance/endurance test. The duration of the low temperature test is 72 hours, with the performance ratings determined from measurements recorded during the final 12 hours. The standard allows for the low temperature test to be performed at any temperature specified by the manufacturer; although the industry has since adopted -25°C as the default temperature. Rating tests are performed at the air flows specified by the submitter. As noted above, cooling tests and a low temperature performance/endurance test are optional.

3 DUAL CORE ENERGY RECOVERY SYSTEM

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.

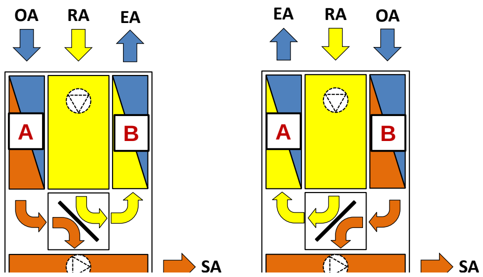

Figure 1. Principle of function – sequence 1 (left) and sequence 2 (right)

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.

4 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.

5 EXTENDED MONITORING IN THE ARCTIC

The dual core ERV unit tested in the Lab and the twin housing has been deployed and monitored in Canada's Arctic to prove its long-term performance and resilience. The monitoring in the Arctic was structured around instrumenting one dual core ERV installed in a mechanical room of a Triplex on CHARS campus in Cambridge Bay (Nunavut) with a dedicated data logging system, as shown in Figure 3. The extended monitoring was undertaken with measurement of the following parameters; 4 relative humidity and temperature probes installed at four locations (supply inlet and outlet, and exhaust inlet and outlet) in the duct, two differential pressure through each heat exchanger, two multipoint air flow sensors were installed in-duct to measure supply and exhaust airflows, and three signals to monitor damper position and fan speeds.

Figure 3. Triplex and deployed dual core ERV on CHARS campus in Cambridge Bay, NU

6 RESULTS AND DISCUSSION

6.1 Ventilation

The typical daily single ERV and dual core ERV supply and exhaust airflows are presented in Figure 4 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 4. 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 4.

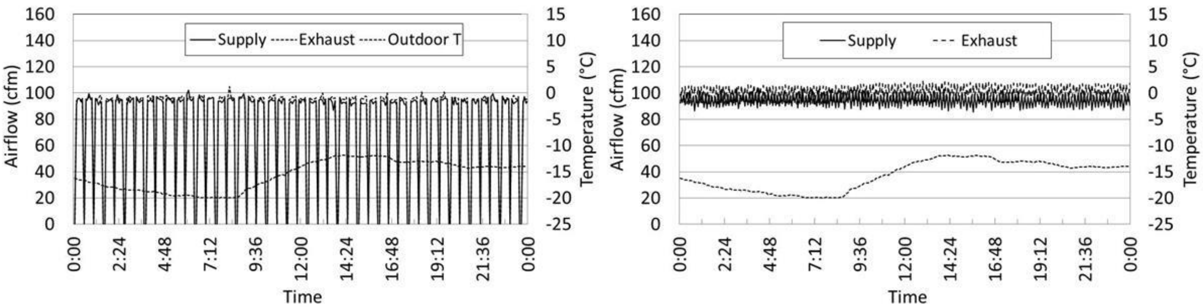

Figure 4. Measured airflows from side-by-side testing, Reference House (left) and Test House (right)

The single core ERV uses a defrosting method presented in Table 2. 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 5 along with the minimum and mean outdoor temperatures.

Table 2. 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

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.

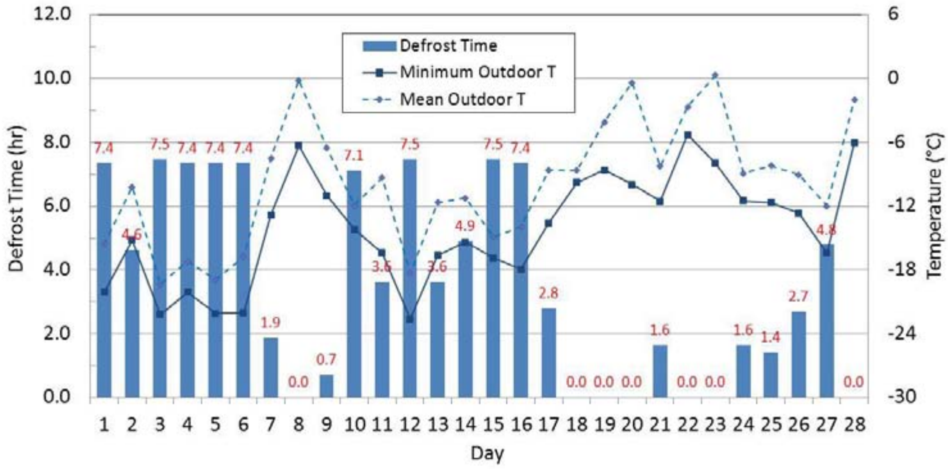

Figure 5. Daily single core ERV defrost time during winter 2019 testing

6.2 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 6 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.

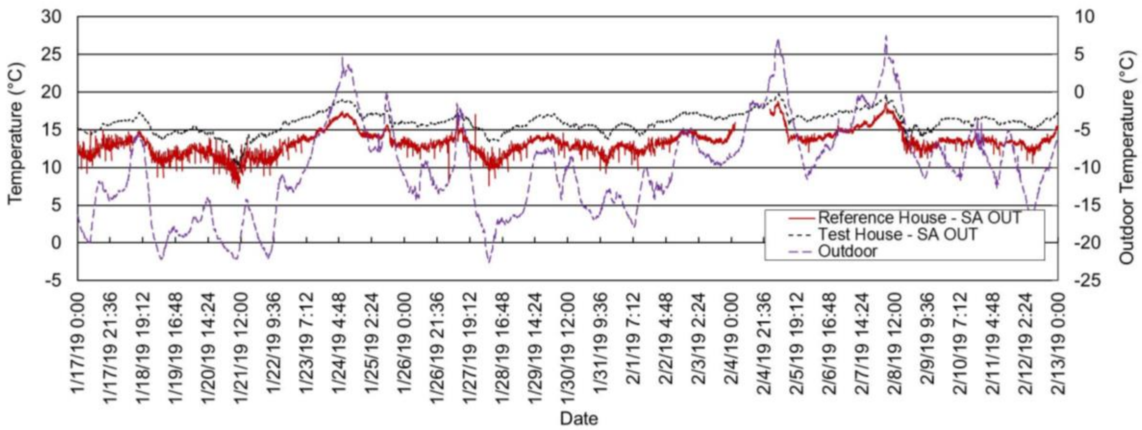

Figure 6. Measured supply air temperature from side-by-side testing

6.3 Effectiveness

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.

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

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.

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 7 and Figure 8. 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.

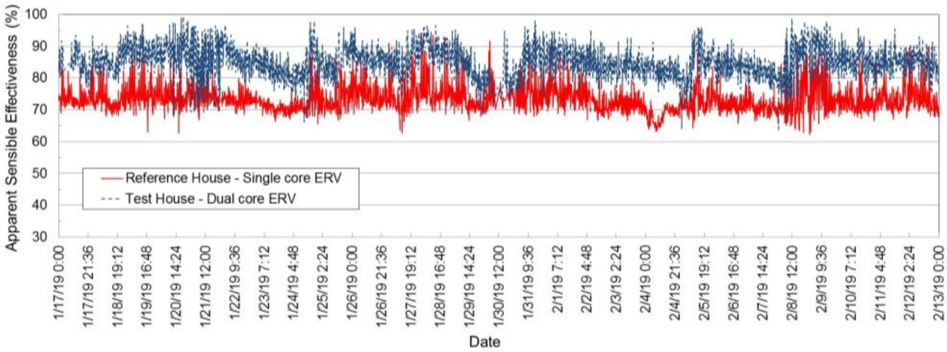

Figure 7. Calculated apparent sensible efficiencies

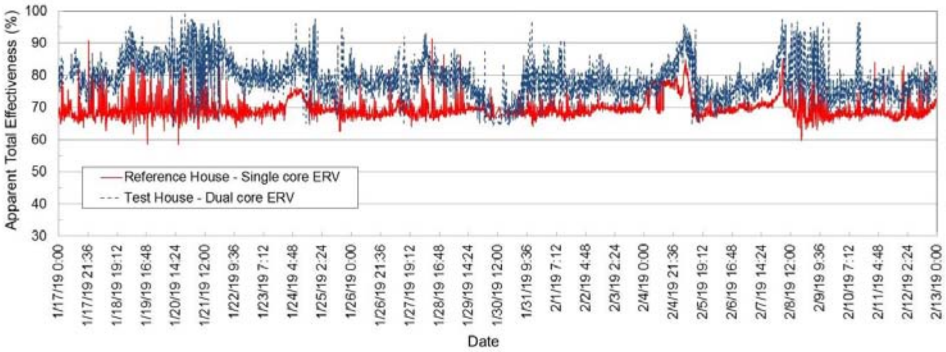

Figure 8. Calculated apparent total efficiencies

6.4 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 ERV experiment consumption from the calculated test house (with single core ERV) benchmark consumption, as shown in Figure 9. The average whole-house energy saving when operating the dual core ERV compared to the benchmark ERV over the period of the study was 5.0%.

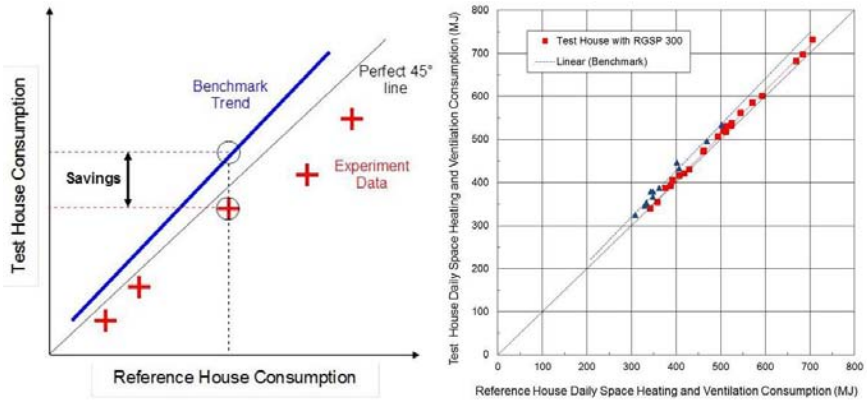

Figure 9. Energy saving, method (left) and results (right)

6.5 Performance in the Arctic

The monitoring of the dual core ERV in the Arctic started June 2017 and continue to April 2020, already tested over two winters 2017-18 and 2018-19. Through this extended field monitoring in the Arctic, we were able to verify the performance and resilience of the technology in a real northern environment, advance confidence in northern applications of this new technology and collect the operational evidence that northern housing corporation and stakeholders require deploying this innovative technology in the north.

The measured supply and exhaust airflows from extended monitoring of the dual core ERV unit in Cambridge Bay (Nunavut) are shown in Figure 10**.** The plot was for the week of December 31st, 2018 – January 6th, 2019 where the outdoor temperature was between -19°C and -36°C. The dual core ERV was slightly unbalanced, experienced very few air exchange reductions, but in general was frost-tolerant, capable of withstanding an outdoor temperature as low as -35°C without deteriorating its ventilation performance (no significant supply flow reduction) and able to provide a continuous supply of outdoor air.

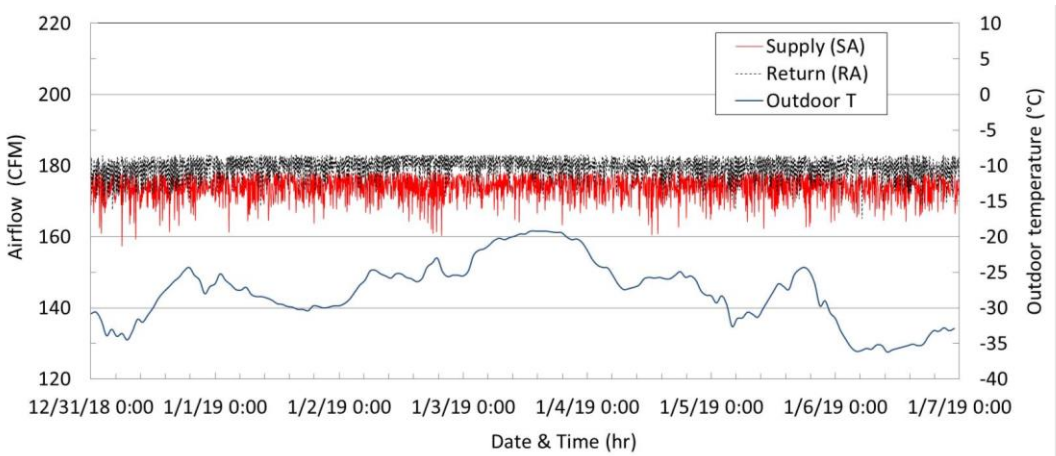

Figure 10. Measured airflows from extended monitoring in Cambridge Bay (Dec. 31, 2018 to Jan. 06, 2019)

A typical measured air temperature at the inlet/outlet of supply and exhaust airstreams and outdoor temperature are presented in Figure 11. The plot was for the week of December 31st, 2018 – January 6th, 2019. The supply air temperature from the dual core ERV to indoor ranged from 14.5°C to 19.2°C with a mean value of 17.2°C. The cycling of the outdoor air (OA) and exhaust air (EA) is caused by cycling damper periodically directing warm air and exhaust air through one of the two heat exchangers. The exhaust air temperature was below 20°C, the unit ran in energy recovery mode with damper cycling every 60 seconds, periodically directed warm air through one of the two cores while outside air gained heat from the heated plates in the other core.

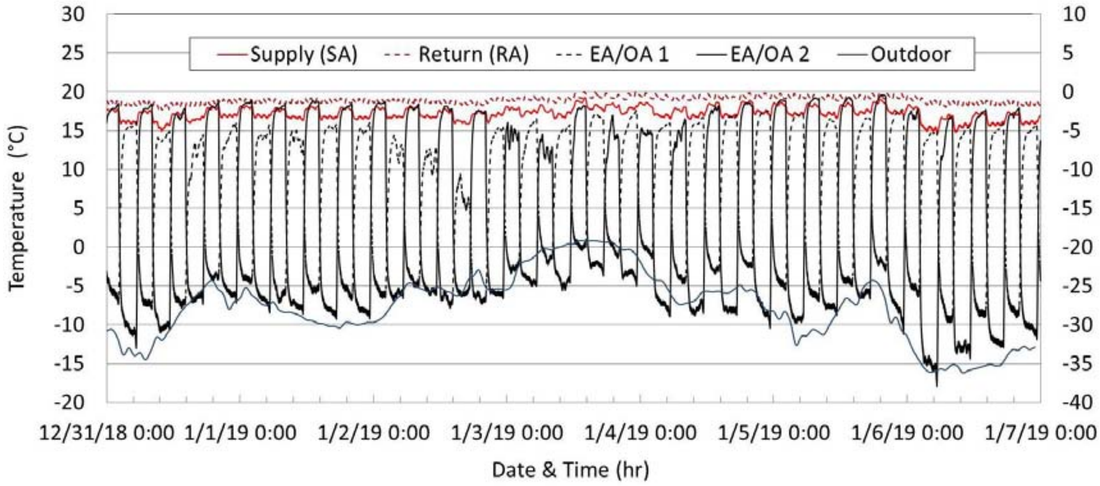

Figure 11. Measured air temperatures in Cambridge Bay (Dec. 31, 2018 to Jan. 06, 2019)

7 CONCLUSIONS

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 (a difference of 12 percentage points) and ATE (a difference of 9 percentage points) 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 per day (up to 7.5 hours) defrosting during cold days (outdoor temperature below -10°C) 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 5% (24.6 MJ/day). The ongoing extended monitoring of the dual core ERV in the Arctic over already two heating seasons (2017-18 and 2018-19) showed that the technology was frost-tolerant and capable of withstanding temperature below -40°C for long periods without deteriorating its thermal and ventilation performances, and provided continuous supply of outdoor air. The proven performance and resiliency to harsh Arctic operating conditions demonstrated that the dual core design ERV is a viable solution for ventilation of northern housing that will improve indoor air quality and health in Northern and remote communities.

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