PERFORMANCE OF A DUAL CORE ENERGY RECOVERY VENTILATION SYSTEM FOR USE IN ARCTIC HOUSING

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Abstract

The extremes of arctic climate pose severe challenges on home heating and ventilation systems. Heat/energy recovery ventilation (HRV/ERV) systems are types of heating, ventilation, and air conditioning (HVAC) systems that can provide required ventilation rates, and at the same time reduce energy consumption. The performance of conventional HRV/ERV and HVAC systems in cold climates has been inadequate due to equipment failures (frosting, etc.). Conventional HRV/ERV units employ frost protection (pre-heating) or defrost strategies (recirculation of stale air, etc.) that can undermine required ventilation rates and the energy saving potential of HRV/ERV systems. A dual core unit, designed with two parallel heat exchangers and a controlled damper, addresses frost protection by periodically directing warm air through one of the two cores while outdoor air gains heat from the other. This technical paper presents the performance results of a dual core system following a rigorous three-pronged methodology. First, a lab evaluation was conducted by using climatic chambers to simulate indoor and outdoor conditions; identified by certification standard CSA-C439 (CSA Group, 2018) and common conditions in the Arctic. Second, side-by-side testing using twin research houses in Ottawa compared the whole-building performance of a house with a single core ERV and a house with a dual core energy recovery system. Third, extended monitoring of the dual core technology was conducted in Cambridge Bay (Nunavut) to prove long-term performance and resilience. The technology was found to be capable of withstanding temperatures below -30 °C without deterioration in its thermal performance. It was also more frost-tolerant and able to provide continuous delivery of outdoor air to the house.

Introduction

The extremes of the arctic climate pose severe challenges on housing ventilation and heating systems. Energy consumption and demand for space heating for remote community buildings are very high. In the arctic/northern regions of Canada

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the average temperature during winter is -25 °C or below; many northern homes are heated to over 25 °C resulting in significant loads on heating and ventilation systems (Zaloum, 2010). Airtight buildings require energy efficient and effective ventilation systems to maintain acceptable indoor air quality and comfort and to protect the building envelope from moisture damage. Without continuous provision of fresh air, indoor pollutants (carbon dioxide (CO_2), excess humidity, etc.) are kept indoors. This may cause or aggravate problems to occupants' health and comfort, and potentially encourage mold growth. A balanced mechanical ventilation system with heat or energy recovery ventilators (HRV or ERV) is an ideal way to meet Canadian national building code ventilation requirements set in ventilation and indoor air quality standards, and energy efficiency programs.

HRV simultaneously supplies and exhausts equal quantities of air to and from a house while transferring sensible heat between the two airstreams. ERV functions in a similar way to an HRV, but in addition to recovering sensible heat, it also transfers latent heat (moisture) between the exhaust and supply airstreams. HRV/ERV systems allow adequate air exchange without excessive energy losses and are well-known and effective methods to improve energy and ventilation efficiency of residential buildings. However, ventilation of houses can be problematic in the North where frosting is a significant challenge for the heat/energy exchangers in these systems. Frost formation in the exchangers is common in cold regions where the outdoor temperature is below -10 °C. Cold outdoor air can cool the exhaust air stream to well below the freezing point and moisture in the outgoing exhaust air can freeze onto the heat exchanger surfaces and create a layer of frost. The winter temperatures in the far North are much colder than the outdoor test temperature of -25 °C that is typically used by HRV/ERV manufacturers. Certification at very low temperature is an optional test for Home Ventilating Institute (HVI) certification (the manufacturer may also choose to conduct this test at any outdoor temperature below 0 °C).

To date, HRV/ERV performance in harsh cold climates has been inadequate (Rafati et al., 2014) due to:

- equipment failures and conventional problems created by the formation of frost in heat exchangers (partial or full blockage of air flow passages);
- increased pressure drop through the heat exchanger or decreased air flow rate;
- increases in electrical power required to operate the fans;
- decreased heat transfer rate between the two airstreams; and
- cold draughts in the space due to low supply air temperatures.

Conventional HRV/ERV units are usually equipped with frost protection systems such as pre-heating of outdoor air or recirculating return air across the heat exchanger and back into the supply air to the house. These defrost strategies can undermine ventilation standards (resulting in the required air exchange rate not being met) and reduce expected energy saving. The aim of this project is to investigate an innovative dual core ERV system and its use as an alternative technology designed for providing continuous ventilation and addressing the frost protection concerns for housing in the Arctic.

Method

This experimental work involved a three-part approach to the research on the performance of an innovative dual core ERV unit designed for housing in the Arctic. The methodology began with a laboratory evaluation using two environmental chambers to simulate indoor and outdoor conditions shown in Figure 1 (picture on the left). This was followed by side-by-side testing using twin research houses to compare whole building performance between a house with a single core ERV and a house with a dual core ERV unit. The twin houses of the Canadian Centre for Housing Technology (CCHT) are shown in Figure 1 (picture in the centre). Last, the dual core technology was deployed in a triplex, located in the Arctic, for extended monitoring to prove long-term

Figure 1: Facilities used in this study.

performance and resilience (shown in Figure 1, picture above).

Description of the technology

A dual core air handling unit comes with a regenerative cyclic dual core heat exchanger. The exchange based on the cyclic storage and release of energy in the corrugated plates alternately exposed to exhaust and intake air. It includes a supply and an exhaust fan and two plate heat exchangers which act as energy accumulators. In between the cores is a patented damper section which periodically directs warm exhaust air through one of the two cores while outside air gains heat from the heated plates in the other core. The schematic of the unit with the two sequences is presented in Figure 2. During *Sequence 1*, warm exhaust air from indoors charges Core B with heat and Core A discharges heat to supply air. During *Sequence 2*, warm exhaust air from indoors charges Core A with heat and Core B discharges heat to supply air.

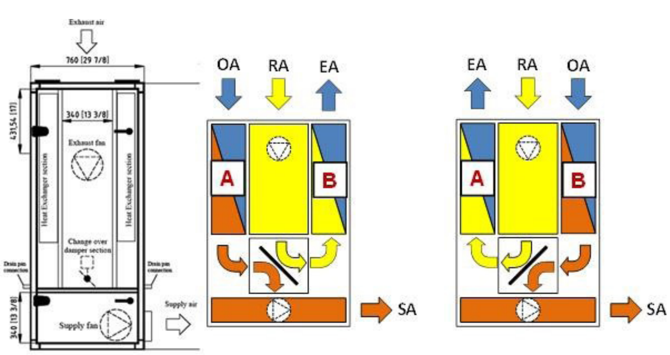

Figure 2: Principle of function – sequence 1 (left) and sequence 2 (right).

To ensure that comfortable air delivery temperatures are achieved in all conditions, 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. The thermostat sequence is based on the exhaust air temperature, if the temperature is:

- lower than 20 °C, the unit will be in energy recovery mode (cycling every 60 seconds);
- higher than 20 °C and the supply air temperature is higher than 15 °C, the unit will be in free cooling mode (cycling every 3 hours); and
- higher than 20 °C and the supply air temperature is lower than 15 °C, the unit will be in energy recovery mode until the supply air temperature becomes higher than 15 °C then it will revert to free cooling mode.

Laboratory testing

An experimental facility was used for the laboratory testing. Cold climate performance tests were conducted using a combination of dual climatic chambers and an HRV/ERV test rig. The HRV/ERV was installed between the indoor and outdoor climatic chambers, as shown in Figure 1 (picture on the left). The outdoor climatic conditions can be varied, ranging from -40 °C to +40 °C ± 1.0 °C, with the capability of maintaining a steady state set point. Simulated indoor climatic conditions can also be varied, ranging from 20 °C to 30 °C ± 1.0 °C, while maintaining a steady state, ambient relative humidity (30% to 60% RH). In order to determine the efficiency and identify when frosting occurs

Table 1: Experimental design.

Tests	Mode	Indoor Conditions	Outdoor T [°C]
1 - 5	Heating mode with standard conditions identified by CSA-C439/HVI	22 °C & 40 % RH	0, -10, -20, -30, -35
6 - 10	Heating mode with identified northern indoor conditions	25 °C & 55% RH	0, -10, -20, -30, -35

in the dual core unit, several properties were measured at different locations inside the unit. These included measuring the:

- supply and exhaust airflows using airflow elements installed in the supply and exhaust ducts;
- pressure drops through heat exchangers A and B using pressure transducers; and
- temperature and relative humidity of the air at the inlets and outlets of the supply and exhaust (return) airstreams using relative humidity and temperature probes purchased calibrated over a temperature range of -40 °C to +40 °C and over an RH range of 10% to 90%.

A series of experiments were conducted to gather data on the thermal and ventilation behaviour. Data were also gathered on the performance of a dual core ERV unit when subjected to steady state indoor and outdoor climatic conditions. Results obtained from these experiments were used to evaluate the sensible and total efficiencies, and the impact of potential frost build-up on both the thermal and ventilation performance of the technology. The conditions set in the indoor chamber were identified by certification standard CSA-C439 (CSA Group, 2018) (presented in Table 1 for tests 1 to 5) and by realistic indoor conditions for northern homes (presented in Table 1 for tests 6 to 10). To challenge the unit under test to extreme cold outdoor temperatures, the conditions in the outdoor chamber varied from 0 °C down to -35 °C. The laboratory testing was done with twin research house total ventilation requirements calculated based on the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) ventilation Standard 62.2 for acceptable

Figure 3: Side-by-side testing using the Canadian Centre for Housing Technology (CCHT) twin research houses.

Figure 4: Triplex on CHARS Campus and deployed dual core unit and dedicated data logging system.

indoor air quality (ASHRAE, 2016). Balanced supply and exhaust airflows were set at 2.83 ± 0.14 m^3/min (100 ± 5 cfm), following the experimental design presented in Table 1.

Side-by-side testing

The CCHT's twin research houses shown in Figure 3 were used for the comparative side-by-side testing (Ouazia et al., 2006). The testing compared a dual core ERV (installed in the Test House) and conventional single core ERV (installed in the Reference House). The twin-house research facility features a "simulated occupancy system". The simulated occupancy system, based on home automation technology, simulates human activity by operating major appliances (stove, dishwashers, washer and dryer), lights, water valves, fans, and other sources simulating typical heat gains.

The simulation schedule is typical of activities that would take place in a home with a family of two adults and two children. The heat given off by humans is simulated by two 60 W (two adults) and two 40 W (two 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 meters (gas, water and electrical). The DAS captures a clear history of the house performance in terms of temperature, humidity and energy consumption. The side-by-side testing involved installing the dual core ERV unit in the Test House basement and making no other modifications to the Reference House with the high efficiency single core ERV originally installed in each house. Following installation, the dual core unit was programmed to match the single core ERV supply and exhaust airflows. The performance of the two houses side-by-side was monitored during the 2017 heating season.

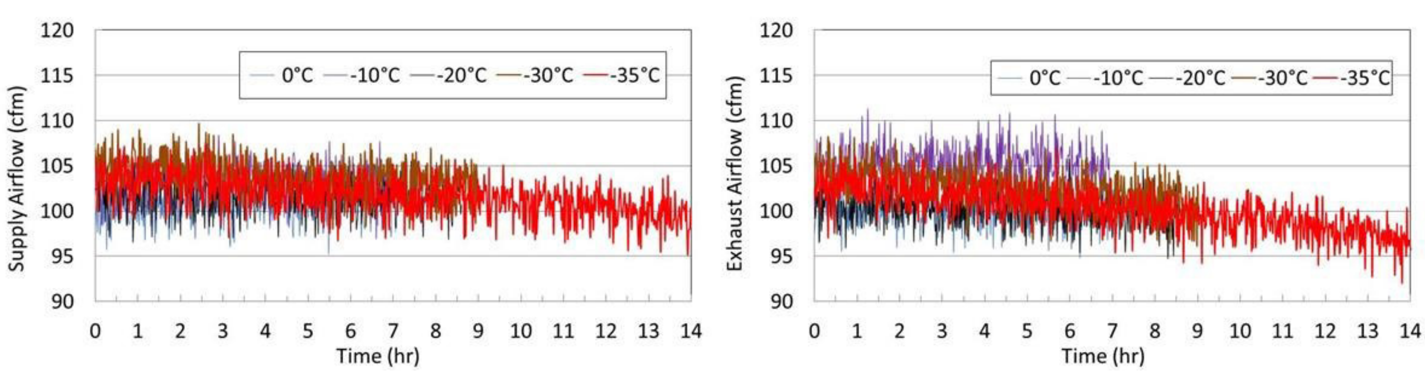

Figure 5: Measured supply (left) and exhaust (right) airflows under northern indoor conditions.

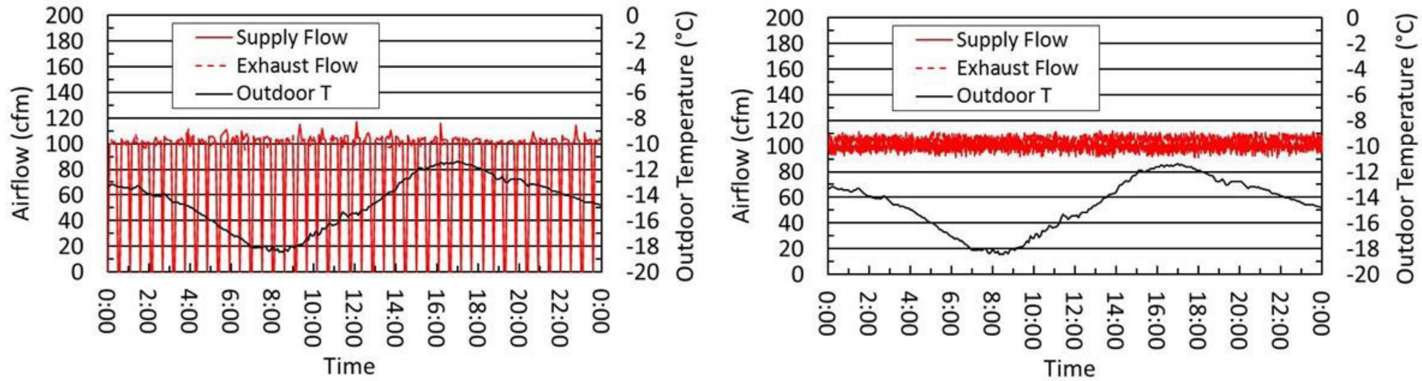

Figure 6: Measured airflows from side-by-side testing under northern outdoor conditions reference house (left) and test house (right).

Northern field monitoring

The monitored dual core ERV unit installed in the mechanical room of a triplex on the Canadian High Arctic Research Station (CHARS) Campus in Cambridge Bay (Nunavut) is shown in Figure 4. The installation of the unit and the dedicated data logging system occurred in March 2017 and long-term monitoring began in June 2017. The extended monitoring captured two full winter seasons: 2017–2018 and 2018–2019.

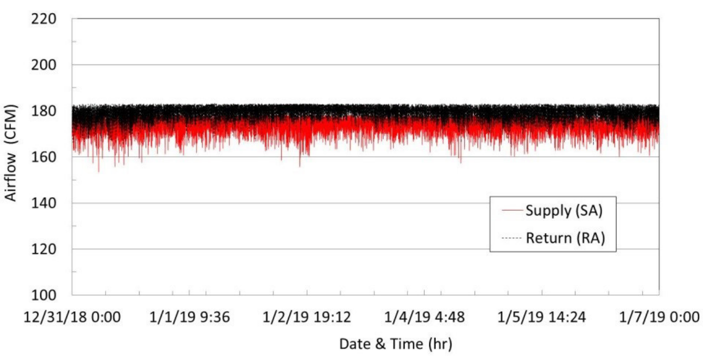

Figure 7: Measured airflows from extended monitoring in Cambridge Bay (December 31, 2018 to January 06, 2019).

Results and Discussion

Ventilation

In the laboratory testing, the measured supply and exhaust airflows showed no signs of flow restriction due to frost occurrence; neither at conditions used for certification to CSA-C439 (CSA Group, 2018) nor at conditions described by the Home Ventilating Institute (HVI, 2016). The tests results associated with northern indoor conditions showed a low decrease in supply and exhaust airflows starting at outdoor temperatures below -20 °C, as shown in Figure 5. The decrease became more pronounced during the longest test done at an outdoor temperature of -35 °C.

The side-by-side testing using the twin houses clearly showed no sign of frost problems on the dual core ERV (as shown on the right plot of Figure 6). It also showed the dual core ERV continued to provide outdoor air throughout Ottawa's cold testing days, without stopping to defrost; unlike the single core ERV which had to spend hours defrosting (as shown on the left plot of Figure 6). The supply and exhaust airflows are presented in Figure 6 in red and outdoor temperature presented in black.

The frequent defrost cycles of the single core ERV led to a reduced amount of outdoor air delivered to the Reference House. This, in turn, led to a situation where the Reference House was not meeting the ventilation requirements. This is a common situation for single core HRV/ERV units installed in extremely cold climates. The measured supply and exhaust airflows from extended monitoring of the dual core ERV unit in Cambridge Bay are shown in Figure 7.

The dual core ERV was slightly unbalanced and experienced very few air exchange reductions. However, in general, it was capable of withstanding

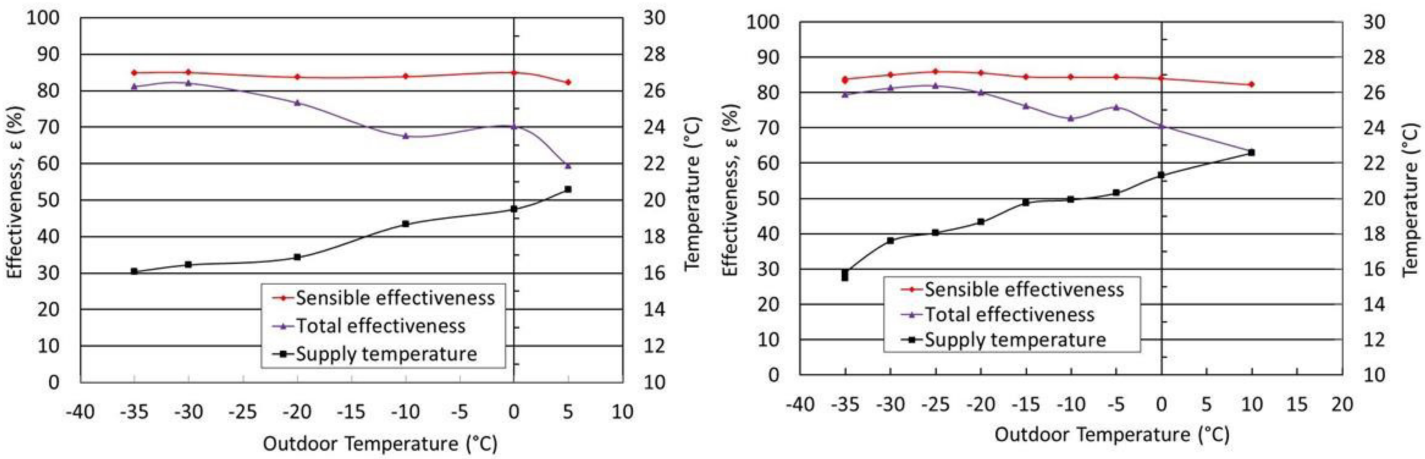

Figure 8: Dual core ERV mean ASE, ATE, and supply air temperature from CSA-C439 testing (left) and northern conditions (right).

an outdoor temperature as low as -35 °C without deteriorating its ventilation performance (no flow reduction). It was also able to provide a continuous supply of outdoor air.

Thermal performance

The apparent sensible or total effectiveness of a heat/energy recovery system is a standard measure of performance. Apparent sensible effectiveness (ASE) measures the ability of an HRV/ERV unit to recover available sensible heat. Apparent total effectiveness (ATE) measures the ability of an HRV/ERV unit to recover available total (sensible heat + latent heat) heat. ATE is calculated by dividing the heat/energy recovered (in the supply air stream) by the total available heat/energy (difference from the interior to the exterior). The effectiveness (ε) of the dual core ERV in transferring sensible and total energy from the exhaust airstream to the supply airstream was calculated for an outdoor temperature range mentioned in Table 1, using the Equation (1). Where, Ms is the supply mass flow

$$R_{eco}(T) = R_{ref}\mathrm{e}^{E_0\left(\frac{1}{T_{ref}-T_0}-\frac{1}{T-T_0}\right)}$$

rate, Mmin is the minimum of the exhaust and supply mass flow rate, and X is the dry-bulb temperature or enthalpy at the respective supply air inlet from outdoor, supply air outlet to indoor, and exhaust air inlet from indoor.

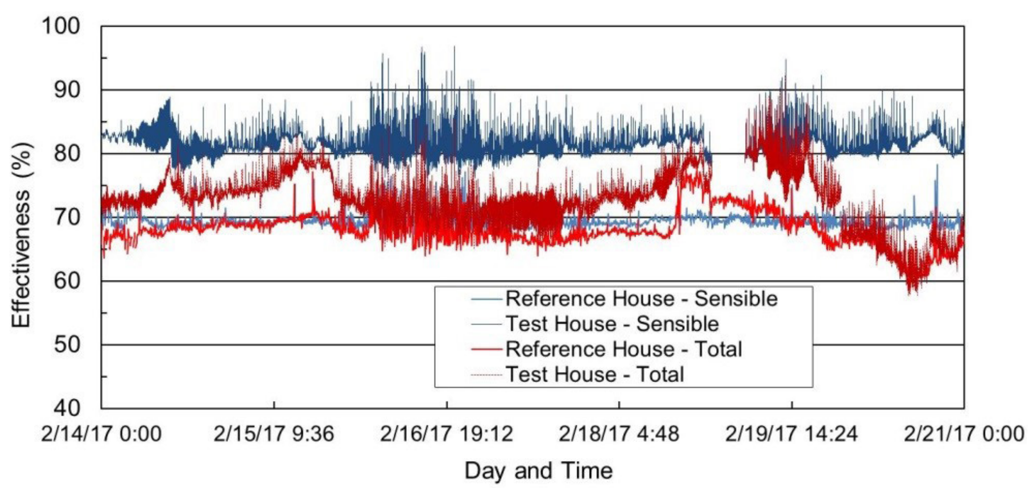

Figure 9: ASE and ATE from side-by-side testing using the CCHT twin houses.

Figure 8 presents the overall thermal performance in terms of ASE, ATE, and supply air temperature from laboratory testing using two climatic chambers. These results represent the simulated indoor condition identified by certification standard CSA-C439 (CSA Group, 2018) (plot on the left) and those identified in the North (plot on the right).

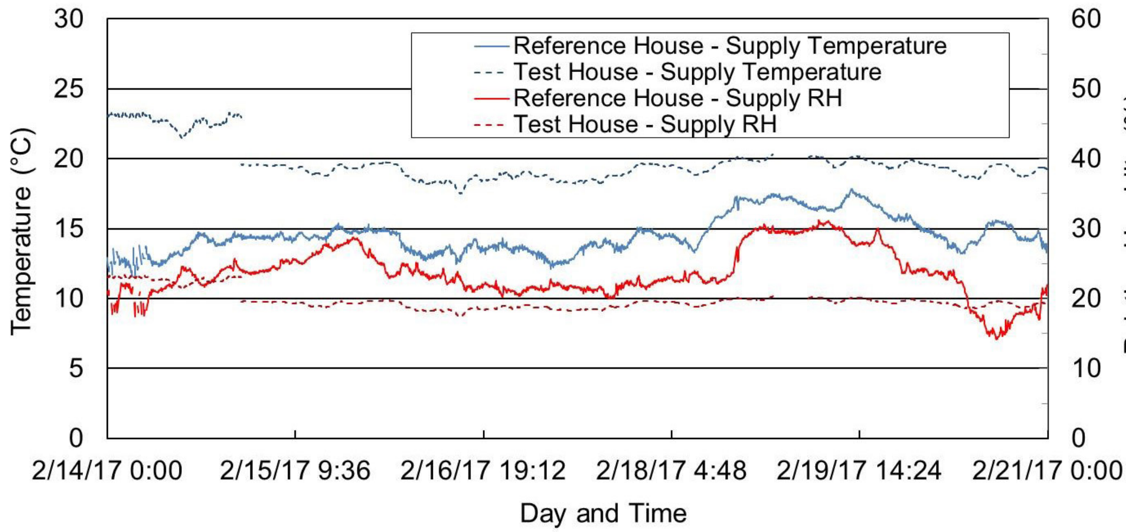

Figure 10: Measured supply air temperature from side-by-side testing.

The calculated ASE measures from testing done with indoor operating conditions identified by CSA-C439 (CSA Group, 2018) ranged from 82.2% to 93.6% (mean = 86%) for the dual core ERV. The calculated ASE for the dual core ERV were much higher than the manufacturers claimed for conventional single core HRV/ERV units. This can be attributed to the regenerative cyclic core heat exchanger and thick aluminum plates heat exchangers which act as heat accumulators. The values increased with decreasing outdoor temperature, and were closer to the calculated values of ASE measures at outdoor temperatures lower than -20 °C. The calculated ATE measures for the same indoor operating conditions identified by CSA-C439 (CSA Group, 2018) ranged from 59.4% to 88.1% for the single core ERV. Conventional single core ERV units are not certified for outdoor temperatures below -25 °C and often their calculated ATE drops below 70% for outdoor temperatures below freezing point.

The ASE and ATE of both single core and a dual core ERV obtained from the CCHT side-by-side testing are presented in Figure 9. The calculated ASE of the dual core ERV had an average value of 81.5% and

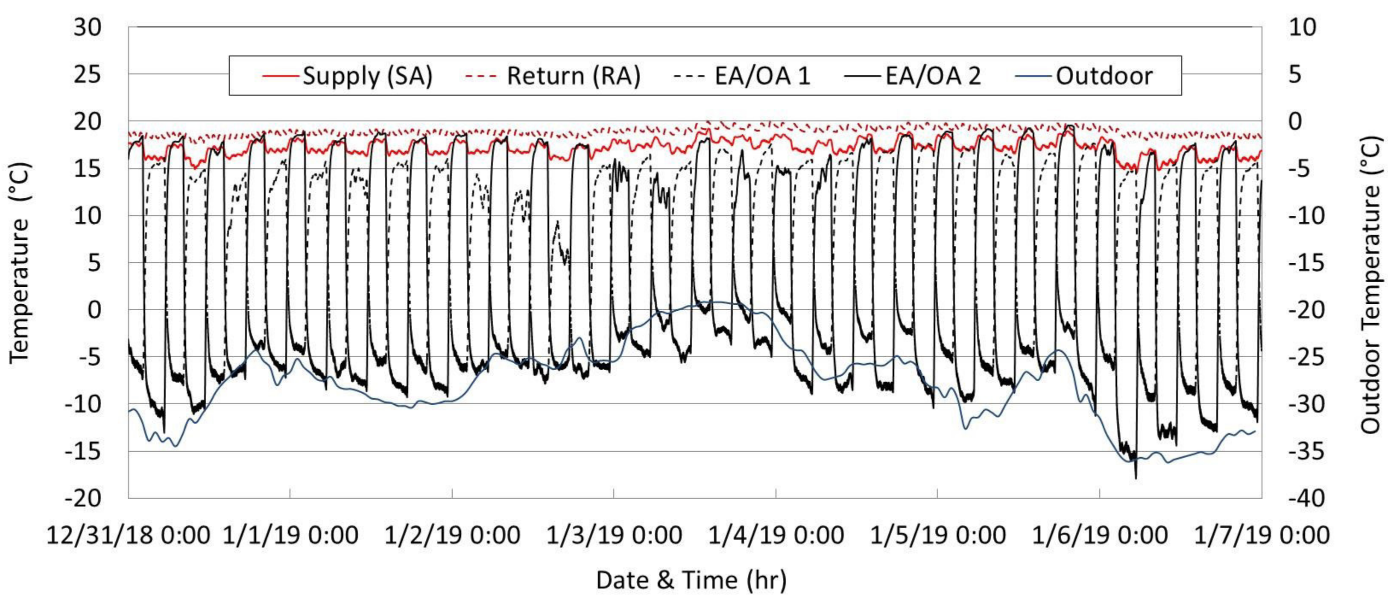

Figure 11: Measured air temperatures in Cambridge Bay (December 31, 2018 to January 06, 2019).

ranged from 76.2% to 96.9%. The single core ERV in the Reference House had an average ASE of 69.5% and ranged from 65.9% to 78.3%, a difference of at least 10 percentage points. The ATE, which takes into account the latent heat of the single core ERV, varied between 60.5% and 77.7%, with an average value of 68.1%. The dual core ERV unit had an ATE between 57.7% and 92.3%, with an average value of 72.7%, slightly higher than the single core unit. Overall, results showed clearly that the dual core ERV unit (in the Test House) outperformed the single core ERV (in the Reference House) in terms of apparent sensible and total efficiencies.

The laboratory testing has shown that the measured supply air temperatures for indoor operating conditions identified by CSA-C439 (CSA Group, 2018) ranged from 15.9 °C to 20.6 °C. The measured supply air temperature for northern operating indoor conditions ranged from 15.3 °C to 22.8 °C. As expected, the values decreased with lower outdoor supply air temperature. At -35 °C outdoor temperature the supply air temperature was 15.3 °C. This is fairly low and requires a provision for tempering by either blending the supply air with room air or preheating it before direct delivery to the occupied spaces.

The CCHT side-by-side testing has shown that the supply outlet air temperature (presented in Figure 10) from the single core ERV in the Reference House varied between 11.5 °C and 17.9 °C. Daily average values ranged from 13.4 °C to 16.6 °C and the average value over the testing period was 14.6 °C. The supply outlet air temperature from the dual core ERV in the test house varied between 17.5 and 20.3 °C. Daily average values ranged from 18.7 °C to 19.6 °C and the average value over the testing period was 19.2 °C. The temperature of the supplied air to the house was higher (3 °C to 6 °C) from the dual core unit than the single core unit. This was due to the much higher ASE of the dual core unit (> 80%) from regenerative cyclic dual cores. This means that the dual core technology is more efficient in recovering heat/energy.

Changes in house performance due to the innovation were addressed through a comparison of the Test House performance (with dual core ERV) to the Reference House performance (with single core ERV). The recorded Test House and Reference House energy consumptions included: heating energy consumption (furnace natural gas consumption), electrical consumption of furnace fans, and electrical consumption of single core and dual core ERV fans. During a one-week period of side-by-side testing, the average whole-house heating and ventilation energy savings, when operating the dual core ERV compared to the benchmark ERV, was 6.2%.

From extended monitoring in Cambridge Bay of the dual core RGSP 300, Figure 11 presents measured air temperatures at the inlet/outlet of supply and exhaust airstreams and outdoor temperatures. The plot is for the week of December 31, 2018 to January 6, 2019. The outdoor temperature was between -19 °C and -36 °C and 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 the cycling damper periodically directing warm air and exhaust air through one of the two heat exchangers. The extended monitoring of the dual core ERV on the CHARS Campus in the Arctic has proven its performance and resiliency in a real northern environment. It was frost-tolerant, capable of withstanding outdoor temperatures below -35 °C, and of providing continuous supply of outdoor air.

Conclusions

This rigorous investigation has shown that, in comparison to a conventional single core ERV, the dual core ERV system had higher ASE and ATE, was more frost-tolerant, and was capable of withstanding an outdoor temperature below -30 °C. The dual core design showed no sign of frost problems, provided a continuous supply of outdoor air, and was capable of supplying air at temperatures up to 6 °C higher than the air temperature supplied by a single core ERV. Under extreme weather conditions, the supply air temperature dropped below an acceptable temperature. To correct this, a post-heating system before supplying air to the occupied space (indoor) would be required. However, the dual core ERV did not freeze and continued to operate without reduction in air exchange. Future work will focus on enhancing the dual core technology to make it a demand-controlled ventilation system, capable of adjusting the ventilation rate based on indoor needs (overcrowding, high activities, etc.).

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