Experimental comparison of performance between single and dual core energy recovery ventilation systems

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Abstract. In cold climates, the defrost strategies of the dominant conventional single core heat/energy recovery ventilators (HRVs/ERVs) involve the recirculation of return warm air across the heat exchanger core and back into the supply air for the house. In harsh cold climates, this type of defrost strategy can undermine ventilation performance. A dual core ERV design could overcome this issue by providing continuous ventilation. It has a potential to perform better than a conventional single core unit and meet the rigorous requirements for operation in the Canada's North. This paper provides an experimental comparison of the efficiency between single and dual core ERVs using the twin houses at the Canadian Centre for Housing Technology (CCHT) as a test bed. The side-by-side testing also provides valuable data to measure the impact of the installation of a dual core ERV in a real residential application. Both houses were operated identically and monitored for a range of winter weather conditions. Changes in test house performance due to the innovative dual core design were observed and compared to the performance of the reference house. The parameters that were compared include: efficiency, airflow, indoor temperature and relative humidity, and energy consumption. This paper discusses the effectiveness of the dual core design ERV, energy use of the house and the ventilation rate.

Keywords: Energy recovery ventilator, Dual core, Residential, Cold Climate.

1 Introduction

Every home needs a ventilation system that provides enough outdoor air to keep the occupants healthy, remove odors, dilute indoor pollutants, and lower the indoor relative humidity. There are many ventilation options available, such as balanced ventilation system with an air-to-air heat/energy recovery system (HRV/ERV). Air-to-air heat recovery is the process of recovering energy from an airstream at a high temperature to an airstream at a low temperature. This process is important for maintaining acceptable indoor air quality (IAQ) while maintaining low energy costs and reducing overall energy consumption. However, ensuring proper ventilation while minimizing energy costs can be a challenge for housing in Canada's North due to several factors including harsh cold climate conditions and frequent overcrowding. Conventional single core units require de-icing in cold climate applications and when installed in a house in Canada's North, they frequently underperform and fail [1, 2, 3, 4]. The conventional frost protection mechanisms in an HRV/ERV is to recirculate the exhaust warm air (interrupting the flow of the exhaust air and redirecting the stale warm air back into the house) to defrost the core. The exhaust air heat loss is a considerable part of the total heat loss in cold climates. During the defrost cycle, no outdoor air is delivered to the house by the HRV/ERV. These shortcomings can undermine the outdoor air requirements of residential ventilation standard [5], and can result in deteriorated IAQ and unhealthy living conditions for the occupants. Most single core heat recovery technologies suffer from the same basic drawback. In extreme cold temperatures, frost forms on the exhaust side of the heat exchanger. This dramatically reduces the heat recovery effectiveness and drives up true operating costs. A new design of ERV system with dual core exchangers periodically direct warm air (return air) through one core (heat exchanger), while outdoor air gains heat from the other core, could address the frost protection concerns and overcome the challenges faced by conventional single core heat/energy recovery ventilators in Canada's North. This paper presents the performance and operational aspects of a dual core ERV through a comparative side-by-side testing with a conventional single core ERV.

2 Methodology

The side-by-side testing methodology in the Canadian Centre for Housing Technology (CCHT) twin houses enabled a whole house evaluation of the impact of the dual core ERV. Both single core and dual core ERVs were operated for seven days to undertake a comparison between the whole house energy performances of the test house with the dual core ERV to the reference house with the single core ERV.

2.1 Experimental facility – CCHT

The CCHT research facility shown in Fig. 1, consists of two identical research houses the r*eference house* and the *test house*. They were built to the R-2000 standard [6] and feature identical simulated occupancies. The houses are extensively monitored for energy performance and indoor environmental conditions. These houses have been calibrated and are very nearly identical [7, 8]. The *test house* is modified by using innovative energy saving components or systems that are being assessed – the dual core ERV in this case. The resulting change in performance was documented relative to the benchmark configuration. The CCHT twin houses are fully instrumented and are unoccupied. To simulate the normal internal heat gains of a lived-in house, these houses feature identical 'simulated occupancies', activated by the state-of-the-art electronic controls used in home automation packages. An important and unique feature of the Twin House facility is its simulated occupancy system, with over 60 on/off events per day. The system is based on home automation technology and simulates the activities of a family of two adults and two children. Electrical consumption is typical for a family of four and hot water draws are set in accordance with ASHRAE standards for sizing hot water heaters. Simulated events include: the operation of major appliances (dishwasher, stove, washer & drier), lights, and water draws (shower, bath, kitchen sink). Incandescent bulbs are used to simulate heat gains from humans (60W per adult, 40W per child) at various locations in the house. The simulation occupancy does not include the latent heat gains of the occupants.

Fig. 1. CCHT Houses

The *reference and test houses* are a typical 2-storey wood-frame houses, with 210 m^2 liveable area and built with a cast-in-place concrete basement, and with style and finish representative of current houses available on the local housing market. It has a standard wall with two-by-six construction. They have a high efficiency sealed combustion condensing gas furnace, a power vented conventional hot water heater and a heat recovery ventilator, along with a number of well insulated and tight assemblies to complete the R-2000 package. The houses have an air tightness characteristic of 1.5 ach @ 50 Pa, which is 30% tighter than R-2000 requirement. The CCHT research houses are equipped with a data acquisition system consisting of over 250 thermocouples, nine RH sensors, and 23 meters (gas, water and electrical). A computer in the garage reads the sensors every five minutes and provides hourly averages. Meter data and a few other measurements are recorded every five minutes. The data aqusition system captures a clear history of the house performance in terms of temperature, humidity and energy consumption during the test period. A complete set of weather data, including temperature, relative humidity, wind speed and direction and solar radiation, is also available from a nearby weather station.

2.2 Tested Technology

A dual core ERV unit comes with a regenerative cyclic dual core heat exchanger, based on the cyclic storage and release of heat in the corrugated sheets alternately exposed to exhaust and intake air. It includes a supply and an exhaust fans and two cores filled with specially corrugated 0.7 mm thick aluminum plates, 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 aluminum plates in the other core. Before each fan, there is a filter section to filter the air. Heat recovery is automatically activated when called upon. Fig. 2 shows the schematic of the dual core unit with the two sequences.

Sequence 1 – Exhaust air (EA) charges *Core B* with heat from return warm air (RA) from indoor and *Core A* discharges heat to supply air (SA) from outdoor (OA).

Sequence 2 – Exhaust air (RA) charges *Core A* with heat from return warm air (RA) from indoor and *Core B* discharges heat to supply air (SA) from Outdoor (OA).

In addition to the innovative heat recovery strategy described above, an additional control system involving internal damper regulation is also used to ensure that comfortable air delivery temperatures are achieved in all conditions.

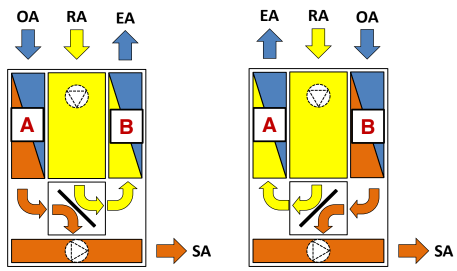

Fig. 2. Principle of function – sequence 1 (left) and sequence 2 (right)

The damper is controlled by the two internal thermostats; GT1 (set to 15°C) in the supply air and GT2 (set to 20°C) in the exhaust air. The sequence includes:
(1) If exhaust air temperature is lower than 20°C, unit is in "energy recovery mode" (cycling every 60 seconds),
(2) If exhaust air temperature is higher than 20°C and supply air temperature higher than 15°C, unit is in "free cooling mode" (cycling every three hours). Note that this mode is not expected to be used often in the Arctic conditions. Monitoring the system performance in actual Arctic conditions in future studies should help verify this.
(3) If exhaust air temperature is higher than 20°C and supply air temperature lower than 15°C, unit is in "energy recovery mode" until the supply air temperature becomes higher than 15°C then it will return back to "free cooling mode".

3 Test Procedure

The dual core ERV and conventional single core ERV are shown in Fig. 3 and were respectively installed in the test house and reference house respectively.

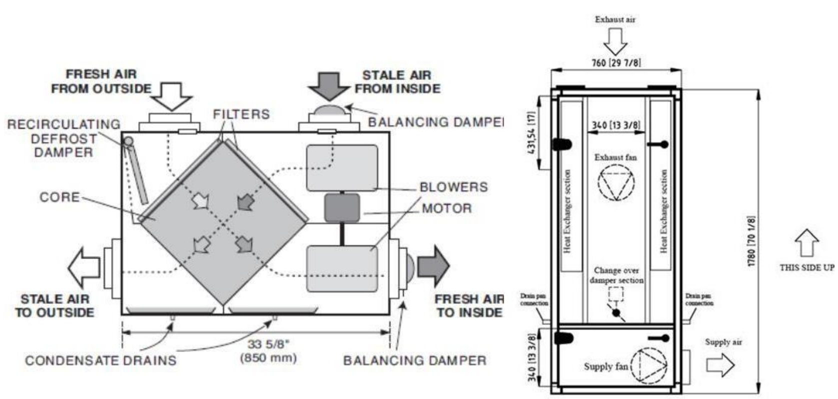

Fig. 3. ERV design – conventional single core (left) and dual core (right)

Both houses were monitored while they are operated identically. Changes in house performance due to the dual core ERV were observed through comparison of test house performance to the reference house performance, for a range of winter weather conditions, over a test period of seven days. During the test, both single and dual core ERVs had airflow of 47.2 L/s (105 cfm). The indoor temperature of the houses was regulated by a standard programmable thermostat located in the main floor hallway at mid-wall height, and set to maintain indoor temperature at 22.5°C and had a narrow band in both houses of ±0.5°C. These thermostats were used throughout the benchmark and any small inconsistencies between the thermostats in each house form part of the benchmark error and are therefore fully accounted for in the experiments. The following performance indicators were monitored on an hour-by-hour basis in both houses during the experiment: airflow, sensible effectiveness, house energy consumption (including electricity for furnace fans, ERV, and heating energy requirements), house air temperature and humidity.

4 Data Reduction

4.1 Effectiveness

The apparent sensible or total effectiveness of a heat/energy recovery system is a standard measure of performance [9-11]. Apparent sensible effectiveness measures the ability of an HRV/ERV unit to recover available sensible heat. Apparent total effectiveness measures the ability of an HRV/ERV unit to recover available total (sensible + latent) heat. It is calculated by taking the heat/energy recovered (in supply air stream) divided by the total available heat/energy (difference from the interior to the exterior). The effectiveness based on the configuration shown in Fig. 4 is calculated using the Eq. (2).

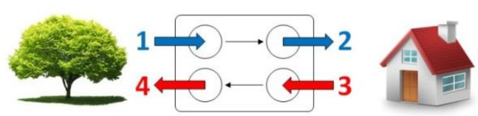

Fig. 4. Air-to-air heat exchanger configuration

$$\varepsilon = \frac{m_s(X_1 - X_2)}{m_{min}(X_1 - X_3)} \quad (2)$$

Where ε is the latent, total or sensible heat effectiveness, X is the humidity ratio, w, total enthalpy, h, or T is the dry-bulb temperature, respectively, at the supply inlet (1), supply outlet (2) and exhaust inlet (3). m_s is the mass flow rate of the supply air, m_e is the mass flow rate of the exhaust air and m_{min} is the minimum value of m_s or m_e.

4.2 Energy saving

The technique used to calculate savings is described graphically in Fig. 5. Each red-cross on the graphic represents the consumption data for a single day of the experiment. For a given day, the reference house consumes a certain amount of energy. Given the amount consumed by the reference house and the benchmark trend line, we can calculate how much energy the test house would consume without the technology installed (shown by the blue line). Savings are calculated by subtracting the measured test house experiment consumption from the calculated test house benchmark consumption. This is equivalent to the vertical distance between the experiment data point and the benchmark trend. The line of best fit is more accurate than the individual points, as they are made up of many points, tending to minimize the effect of random errors. So the benchmark data is first used to develop a characteristic performance line. Once the line is produced at a high level of statistical confidence, it is used to calculate the difference in performance, by subtracting the performance of the technology from the benchmark for each experiment day.

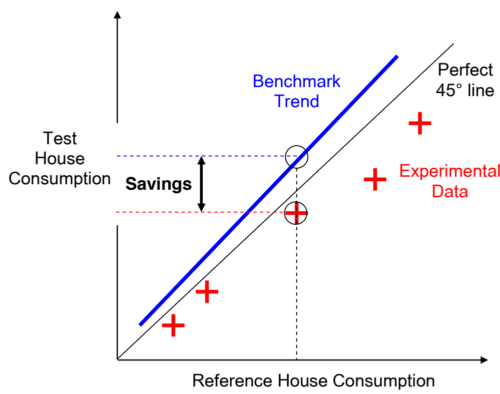

Fig. 5. Graphic representation of the saving method

The reasoning behind this calculation process is as follows. On any given day, some scatter is expected in the results both for the Reference House and the Test House. This scatter appears to be random error. One possible cause is that the houses' heating systems cannot be synchronized. When one house may be at the end of a heating cycle at midnight on one day, and the other house may be at the beginning, resulting in small and opposite errors on both the first and second days when this occurs.

When studying moderate change to the house, on any given day, the error in one house can be the opposite direction of the other house and vice versa. When looking at differences in experimental performance due to a technology change, that relative error can be large compared to difference due to the technology. To reduce the effect of this random scatter, a statistical technique is used to determine a characteristic line of best fit for the benchmark configuration. This reduces the risk of incorporating random errors on any given day of the benchmark, and also benchmarks systematic errors that are not due to the technology being studied. The line of best fit is much more accurate than the individual points, as they are made up of many points, tending to minimize the effect of random errors. So the benchmark data is first used to develop a characteristic performance line. Once the line is produced at a high level of statistical confidence, it is used to calculate the difference in performance, by subtracting the performance of the technology from the benchmark for each experiment day. The uncertainty of the energy saving calculation depends strongly on the length of the test.

5 Results

This section compares the operation of the two houses, in terms airflows, apparent sensible and total efficiencies, delivered outdoor air temperature to the indoor, indoor air temperature and relative humidity, and all components of the energy consumption of both houses.

5.1 Ventilation

Effective ventilation is a vital system in a healthy home. Heat or energy recovery units should continuously deliver the minimum outdoor flow rate required for people and house air needs (total ventilation requirement) and set by the building codes and ventilation standards [5, 12]. A balanced ventilation system, for both exhaust and supply, will give the best results for distributed fresh air through the house. Unbalanced system will exacerbate the negative or positive pressure in the house (pressurization or depressurization of the house), which could have a negative impact on the energy consumption and IAQ. A frequent defrost cycles will also reduce the amount of outdoor air delivered to the house, leading to a situation where the house is under-ventilated and does not meet the ventilation rate requirement. The supply and exhaust airflows through the dual core ERV and the single core ERV were measured during the side-by-side testing period. Daily results for single core ERV (excluding the defrost recirculation of warm stake air) and dual core ERV airflows of a typical day are presented in Fig. 6.

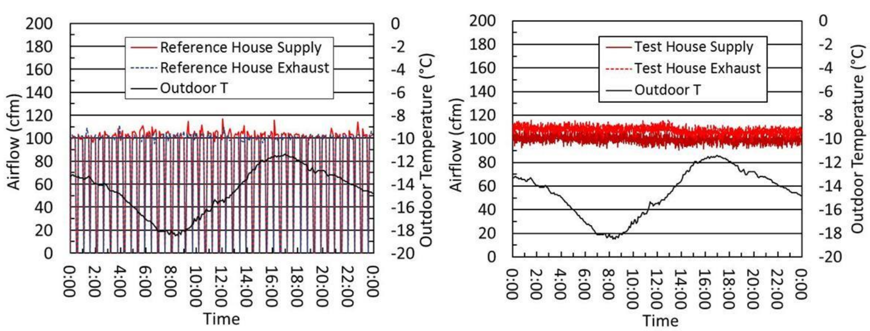

Fig. 6. Daily supply and exhaust airflows

The single core ERV presented fairly balanced supply and exhaust flows and experienced de-icing periods (defrost cycle) to melt ice build-up during the day with outdoor temperature below -10°C. The dual core ERV, with supply and return airflows cycling between two heat exchangers presented also a balanced supply and exhaust flows and did not stop to defrost cycle in the same day under the same weather conditions – so it continued to provide fresh air throughout, unlike the single core ERV.

The single core ERV unit was often in the defrost mode, recirculating stale exhaust warm air to melt frost build-up in the core, and not continuously supplying outdoor air to the house. The duration that a single core ERV spent in defrost mode ("defrost time") that day was 315 minutes (or 5.25 hours). That day the single core ERV was 22% of the time defrosting and not supplying outdoor air to the house. The de-icing cycle duration is strongly dependent on outdoor temperature. Under extreme cold weather conditions single core ERV/HRV unit could have been in defrosting mode for a long period per day, during which time the house would be seriously under-ventilated and not providing the required ventilation rate set by ASHRAE ventilation standard [5] and the National Building Code of Canada [12].

5.2 Effectiveness

The apparent sensible, total efficiencies ε calculated using Eq. (2) of a single and dual core ERVs are plotted in Fig. 7. The calculated sensible effectiveness of the dual core ERV during the side-by-side testing period had an average value of 82%, ranged from 76% and 97%, and with an uncertainty of 3.2%. The single core ERV in the Reference House had an average apparent sensible effectiveness of 69% during the same testing period, ranged from 66% and 78%, and with an uncertainty of 2.8% (difference of at least 10 percentage points). The apparent total effectiveness which takes into account the latent heat of the single core ERV varied between 61% and 78%, with an average value of 68% and uncertainty of 3.9%. The dual core ERV unit had an apparent total effectiveness between 58% and 92%, with an average value of 73% slightly higher than the single core ERV and an uncertainty of 2.5%.

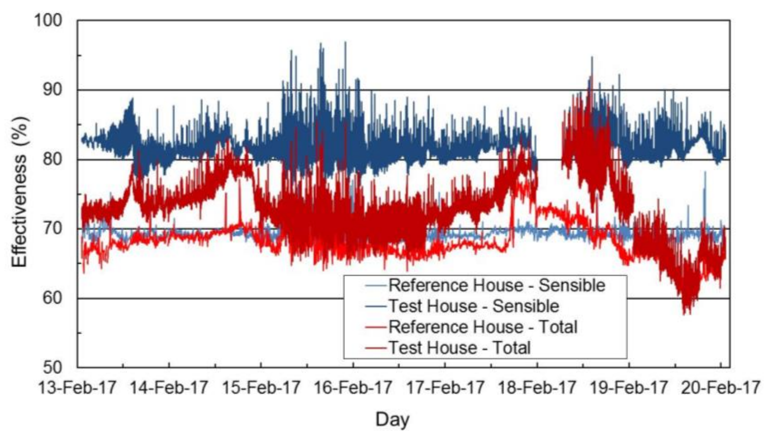

Fig. 7. Apparent sensible and total efficiencies

The daily apparent sensible and total efficiencies during the side-by-side testing showed clearly that the dual core ERV unit over performed the single core ERV in terms of apparent sensible effectiveness, and consistently performed better in term of apparent total effectiveness.

5.3 Outdoor air supply temperature to the indoor

The supply and exhaust airstream conditions were measured both for the single core ERV unit installed in the Reference House and the dual core unit installed in the Test House. The supply outlet air temperature and RH from single and dual core ERVs to the indoor (house) are presented in Fig. 8.

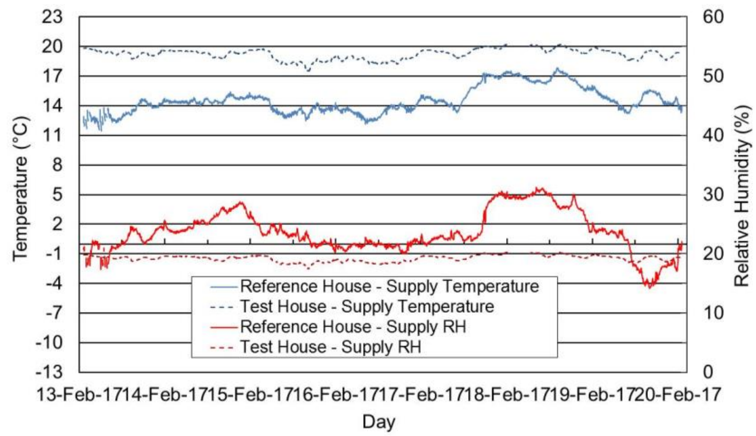

Fig. 8. Outdoor supply temperature and RH to the indoor

The temperature of the supplied air to the house was higher (3 to 6°C) from the dual core unit than the single unit as shown in Fig. 8. This was due to the much higher sensible effectiveness of the dual core unit (higher than 80%) from regenerative cyclic dual core heat exchangers. The air supplied to the return furnace in the reference house is cooler than air supplied to the furnace return plenum in the test house. The daily average difference between the supply from single core ERV (Reference House) and the dual core ERV unit (Test House) ranged from 3°C to 6°C. The supply air to the test house would require 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 higher energy saving. Ventilation air must be introduced into the occupied zone in a way that avoids causing discomfort to the occupants and at acceptable minimum temperatures, 17°C for floor distribution and 13°C for ceiling distribution, as specified by the National Building Code of Canada [12]. The supply outlet air temperature from the single core ERV in the Reference House varied between 11.5°C and 17.9°C and daily average values ranged from 13.4°C to 16.6°C. The average value over testing period was 14.6°C, which is below the acceptable minimum temperature of air that would be introduced to occupied zone; requires tempering of the supplied air. The supply outlet air temperature from the dual core ERV in the Test House varied between 17.5°C and 20.3°C and daily average values ranged from 18.7°C and 19.6°C. The average value over the testing period was 19.2°C, which is higher than the acceptable minimum temperature of air that would be introduced to occupied zone; requires no or less tempering of the supplied air.

5.4 Space heating energy saving

The houses with single core ERVs were first operated to show that they were as thermally identical as possible, before the dual core ERV assessment. Benchmarking the houses occurred over a heating periods in winter of 2017. The benchmark periods were before and after testing with central thermostat set to maintain indoor temperature at 22.5°C. The energy performance of the test house was shown to be very nearly identical to the reference house. This performance comparison forms the benchmark against which dual core ERV can be compared. The real impact of the installation of the dual core ERV in Canadian houses was evaluated for a range of winter temperatures in Ottawa. Changes in house performance due to the innovation were addressed through comparison of the test house performance (dual core ERV) to the reference house performance (single core ERV). The recorded reference house and test house energy consumptions included; heating energy consumption (furnace natural gas consumption) for both houses, furnace fan electrical consumption for both houses, single core ERV fans electrical consumption for reference house and dual core AHU fans electrical consumption for test house. The total daily heating and ventilation energy consumptions are presented in Fig. 9.

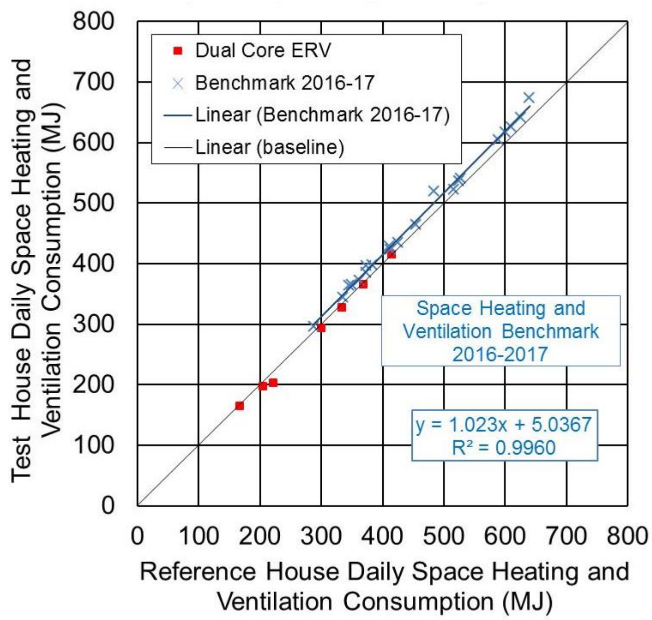

Fig. 9. Space heating and ventilation daily total consumption

Each point on the graph represents a single day of total space heating and ventilation consumption, with the reference house consumption plotted on the x-axis, and the test house consumption on the y-axis. The average energy savings when operating the dual core ERV compared to the benchmark single core ERV over the period of the study was 6.2%.

6 Conclusion

A dual core ERV (with two parallel heat exchangers) was tested during the winter of 2017 in side-by-side testing using the twin houses facility of the Canadian Centre for Housing Technology. In comparison with conventional single core ERV, the dual core ERV had much higher apparent sensible effectiveness (81.2% compared to 69.5% for the single core ERV), and slightly higher apparent total effectiveness (72.7% compared to 68.1% for the single core ERV). In addition to the better effectiveness, it also showed no sign of frost problems after the seven days of weather testing and successfully continued to provide outdoor air throughout cold days without stopping to defrost, unlike the conventional single core ERV which spent hours defrosting over the coldest test days. Under much colder weather conditions (outdoor temperature below -10°C), the single core ERV would spend hours in the defrost mode which could have led to a situation where the house would be under-ventilated. This is a common situation for single core units installed in Canada's Far North. The dual core design ERV with much higher heat transfer effectiveness was capable to provide air at the supply outlet at temperature up to 6°C higher than air temperature supplied by a single core ERV. In comparison with the Reference House with a conventional single core ERV, the Test House with a dual core ERV had similar indoor air temperature (as regulated by the thermostat) and relative humidity and showed saving in heating and ventilation energy consumption, ~6.2% (18.7 MJ/day) decrease on average over the seven day test period. The uncertainty in quantifying potential energy savings depend strongly on the duration of the testing period. As part of this investigation the dual core ERV design technology has been deployed in Canada's Arctic (Cambridge Bay, Nunavut) for extended monitoring to provide evidence on the performance and resilience of the technology in the North.

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