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Experimental study and analysis of an energy recovery ventilator and the impacts of defrost cycle

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ABSTRACT

The potential of conventional heat/energy recovery ventilators have been widely studied, whereas the impacts of defrost cycles are usually neglected. An energy recovery ventilator (ERV) was studied in the Archetype Sustainable House-B (ASH-B) located in Toronto, Ontario. The study provides an experimental evaluation of the efficiency of the ERV unit during normal and defrost operations, as well as its frost resistance to a range of winter temperatures. The parameters that were considered included fan power draw, inlet and outlet air temperatures, humidity, and airflows. Operating the ERV without the defroster revealed a frost resistance of up to −16 °C. In addition, the data analysis of defrost cycle revealed two stages of change of fresh air temperature and humidity, which can be used to predict the thermal performance of the ERV unit under different operating conditions.

1. Introduction

With the current leaning towards energy conservation, new houses have been increasingly built to be airtight energy-efficient (R-2000-certified houses) to minimize heat losses and impacts during operation [1]. However, due to the dilemma between the construction of airtight energy efficient houses to tackle energy conservation and the effort to ensure good indoor air quality within such well-insulated envelopes, heat recovery (HRV) and energy recovery ventilators (ERV) have become critical for maintaining air quality, balancing air pressure and promoting heat conservation [2]. HRVs provide continuous mechanical ventilation and exchange sensible heat between airflows to minimize energy needed to condition the incoming fresh air. In contrast, ERVs operate using the same general principle as the former, but they also take advantage of the humidity difference between airflows to transfer both sensible and latent heat contained within the air.

In cold winter, warm exhaust air inside HRV/ERV units is often cooled below its dew point at which condensation and/or freezing are initiated. Earlier study revealed that the onset temperature of freezing is at supply airflow temperature that ranges from −3 °C to −7 °C for cross-flow heat exchanger and −8 °C to −12 °C for cross-flow energy exchanger [3]. Freezing inside cores eventually impede the exhaust airflow, resulting in lower efficiency of heat recovery and pressurization of indoor spaces [4–6]. Therefore, both HRVs and ERVs used in North America are required to have defrost control to prevent core from freezing and blocking during cold days.

There are many different types of defrost control, and yet none of them is optimal [6]. Currently, preheating the inlet air, reducing the fresh airflow rate, and recirculating exhaust air are the most common and simple defrosting techniques adopted for HRV/ERV. The first approach results in additional energy use especially in arctic climates, and hence, is not economical [5,7,8]. A comparison of defrost techniques by Nasr et al. [6] showed that the second approach can lead to depressurization in building and decreasing indoor air quality for long periods of use. Moreover, the experimental results of the two approaches were studied and reported by Fisk et al. [4]. Exhaust air recirculation is widely adopted in HRV/ERV designs (VanEE, Lifebreath, Lennox, etc.), because it was found to be most appropriate for extremely cold climates [7]. During defrost cycle, warm exhaust air is introduced and recirculated through unit's core to melt ice/frost accumulated on the core surfaces, and the houses remain unvented.

Many studies have focused on the topics regarding the potentials and thermal behaviors of HRVs/ERVs [9–13], whereas the impacts of warm air recirculation are usually neglected. In fact, recirculating indoor air could result in the reintroduction of smelling air and/or carbon dioxide from kitchen, washroom, and other areas of high contamination. In addition, the recirculated air accompanies moisture from the melted ice/frost, which might cause temporarily high indoor humidity level. This paper presents an analysis of experimental data of an energy recovery ventilator

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Nomenclature

A_c	calibrator accuracy
A_s	sensor accuracy
ASH	archetype sustainable house
ERV	energy recovery ventilator
HRV	heat recovery ventilator
RH	relative humidity (%)
T	air temperature (°C)
P_w	partial pressure of water vapor (Pa)
P	atmospheric pressure (Pa)
w	humidity ratio (g/kg)

Greek symbols

ε	relative uncertainty
η	thermal efficiency
η'	thermal efficiency during air recirculation
σ	standard uncertainty

Subscripts

s	sensible
L	latent
fi	fresh inlet
fo	fresh outlet
ei	exhaust inlet

during the defrost cycle, as well as the tolerance of the unit during cold days with a deactivated defrost control.

2. The archetype sustainable house and test facility

2.1. House descriptions

The Archetype Sustainable House-B (ASH-B) is an airtight energy-efficient semi-detached house located at Vaughan, Ontario (see Fig. 1). This house was developed by Toronto and Region Conservation Authority (TRCA) in partnership with the Building Industry and Land Development Association (BILD). The structural features of the house are listed in Table 1. The ASH-B is equipped with a horizontal-loop coupled with ground source heat pump, energy recovery ventilator, and other sustainable and innovative technologies for future practice [14]. In addition, the house has been LEED Platinum certified, and was specially designed and built with advanced materials to minimize heat loss and environmental impacts during operation. Currently, the house is used to demonstrate an affordable, low-energy house that can be mass-produced with a small ecological footprint [16].

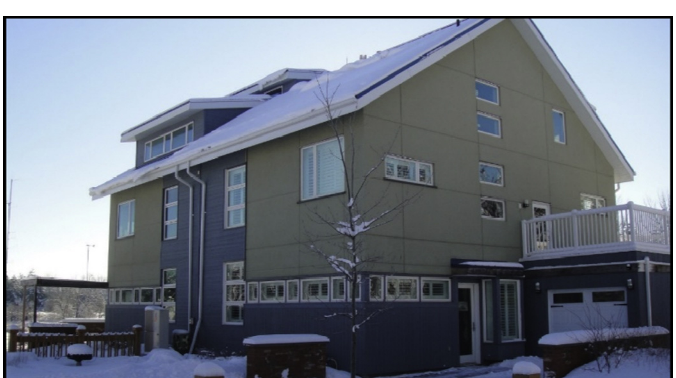

Fig. 1. Archetype sustainable houses.

Table 1
Structural features of the TRCA archetype sustainable house-B [14,15].

Features	House-B
Story	3 and 1 basement
Floor area	321.04 m^2 (3444 ft^2)
Volume	1035.94 m^3 (36584 ft^3)
Above grade walls	RSI 5.64 (R32)
Basement walls	RSI 3.54 (R20)
Basement slab	RSI 1.76 (R10)
Roof	RSI 7 (R40)
Windows	1.59 W/m^2K (0.28 But/hr-ft^2-°F)
Overall UA value*	172 W/K

* Heating at −7 °C outdoor and 21 °C indoor air based on TRNSYS House model.

2.2. Mechanical ventilation system

Ventilation heat recovery has been commonly adopted in maintaining air quality and promoting heat conservation in airtight houses. The ASH-B is equipped with an ERV, allowing both heat and moisture to be transferred from one stream to another through an enthalpy core. Table 2 lists the specifications of the ERV in House-B. The ERV unit consists of an enthalpy based core, two filters at the inlet of both air streams, and an insulated casing with four pipe connections. In addition, the unit uses warm air recirculation as the defrost mechanism to prevent core from freezing when the temperature of the outdoor air is cold. Theoretically, the defrost control activates at outdoor air temperature of −10 °C and below, and it runs 6 min for every 32 min of normal operation. Fig. 2 illustrates the flow configuration during the defrost cycle.

2.3. Sensors and monitoring system

Over 300 sensors of various types were installed in the ASH-B to cover sufficient energy monitoring details. For this study, a Dwyer RHP duct mount air humidity/temperature transmitter with an accuracy of ±2%/±0.2 °C was used at each of the inlet and outlet sections of the ERV unit to measure the air properties of fresh and exhaust airstreams. In addition, the temperature encountered in the experiment was so low, and hence, radiative heat transfer was negligible. The air flow rates of both airstreams were measured using Dwyer 677B differential pressure transmitters with an accuracy of ±0.4% full scale of the output signal (mA). All measurements were acquired at a constant sampling time of 5 s. For flow rate, the value is calculated within the sampling period. Fig. 3 shows the experimental facilities in the TRCA Archetype Sustainable House-B.

3. Experimental procedure

3.1. Normal and defrost operation

A long-term monitoring system within the ASH-B has been implemented to monitor HVAC equipment using an NI based data acquisition (DAQ) system, and stored using Microsoft SQL Server [18]. The ERV unit was operated over four weeks to investigate both low level information (temperature, flow rate, etc.) and high

Table 2
Specifications of ERV [17].

Equipment	Technical information
Energy Recovery Ventilator (ERV) VanEE: Gold Series–2001 ERV	Heat Exchange Surface Area: 14.51 m^2 (156 ft^2)Type: Cross-flowCore Material: Enthalpic transfer mediaEnergy performance: 69% sensible recovery efficiency at 52 L/s (110 cfm) and 0 °C outdoor air temperature45% latent recovery efficiency at 52 L/s (110 cfm) and 0 °C outdoor air temperatureDefrost cycle: 6 defrosting min. per 32 operating min. at −10 °C