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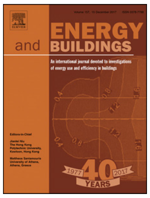

Analysis of the variable heat exchange efficiency of heat recovery ventilators and the associated heating energy demand

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ABSTRACT

Energy recovery ventilators (ERV) have become popular in Korea for their use in minimizing heat loss in ventilation and maintaining indoor air quality (IAQ). The performance of ERV systems is determined by laboratory tests under prescriptive indoor and outdoor conditions. Typically, a fixed heat recovery efficiency of the ventilation system is used in building energy simulations.

In this study, in order to analyze the heat recovery efficiency of an ERV under actual operating conditions, long-term field measurements were performed in a residential building in the winter. The results showed that the enthalpy heat recovery efficiencies fluctuated between 25% and 70% depending on the outdoor conditions. The sensible heat recovery efficiencies were between 30% and 65% and were proportional to the temperature difference between indoors and outdoors. The heat exchange efficiency of ERV was not constant but varied according to changes of indoor and outdoor conditions under actual operating conditions.

A simulation method was used to analyze the effect of the ERV's variable heat exchange efficiency on heating energy demand in the heating season. Two cases were analyzed. Case 2 analyzed the variable heat exchange effectiveness of the ERV based on the field measurements. Case 1 examined the fixed effectiveness proposed by the manufacturer. Simulation results showed that the heating energy demand in Case 2 was 69% higher than that in Case 1. This means that the heating energy demand may be underestimated if the heat exchange efficiency of the ventilation system is assumed to be constant in the simulation.

1. Introduction

In contemporary building practice, there is a tradeoff between energy saving and ventilation, or IAQ. Increasing the ventilation rate will improve the indoor air quality, but an increased ventilation rate will also cause the cooling and heating loads on a building to increase. The two main strategies to reconcile these contradictions are to use heat recovery units and to implement demand-controlled ventilation [1–6]. In a moderate climate in Europe, combined infiltration and ventilation represent about 50% of the total heat loss in well insulated buildings [7]. In addition, the energy demand of heating from ventilation air tends to be about 60% of the total annual energy demand for a building that is well insulated and tightened, as demonstrated by a new building in Germany [8]. Given these circumstances, energy recovery ventilators (ERV) and their efficiency have become the most important issues in low-energy buildings. Ventilation air is a particularly important source of energy loss in nearly zero-energy buildings (nZEBs). Therefore, in residential buildings, mechanical ventilation systems become mandatory [6,9].

A typical ERV in buildings is available to transfer energy between the exhaust air and the supply air. These units are classified as either sensible or enthalpy heat recovery units. Enthalpy recovery units, which can transfer both sensible and latent heat, are more energy efficient than sensible heat recovery units [10]. ERVs have been widely used in Northern European countries because of their potential to reduce heating and cooling energy consumption in buildings [11], and since 2007 they have begun to be widely used in residential buildings in Korea [12]. The performance of ERV is measured by its efficiency or effectiveness. Enthalpy efficiency is determined by lab tests under prescriptive indoor and outdoor conditions (under steady-state conditions). This efficiency is supposed to be a constant value in evaluating the performance

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of ventilation systems with respect to heating and cooling energy demand. However, under real conditions in real houses, enthalpy efficiency is not constant because both indoor and outdoor air conditions can influence its efficiency [13–16].

Some studies used simulation methods to study the performance of ERVs in different weather conditions. Liu et al. [16] analyzed the weighted coefficient equations for describing the performance of ERVs in different climatic zones in China. They concluded that, in most areas in China, the total heat (enthalpy) efficiency of an enthalpy exchanger is determined, for the most part, by the sensible heat efficiency in winter and the latent heat efficiency in summer. Zhou et al. [15] used a simulation method to investigate the performance of an energy recovery ventilator under various outdoor weather conditions and indoor temperature setpoints. Their results showed that the seasonal average ratio of total energy recovery by the ERV to the energy usage of the whole HVAC system was linearly related to the indoor temperature set-point.

Some researchers conducted field measurements to estimate the performance of the ERV. Zhang et al. [17] used an experimental house to analyze sensible/latent heat recovery based on indoor and outdoor conditions. Their results demonstrated that sensible heat recovery increases linearly as the dry bulb temperature difference increases. A similar trend was observed in latent heat recovery with respect to the specific humidity difference. Zhang et al. [18] showed the experimental results of a defrost cycle of an ERV in an experimental house, as well as the sensible and latent heat efficiencies of ERVs during a defrost cycle. Using two research houses in Ottawa et al. [19] showed an experimental evaluation of the efficiency of an HRV for sensible heat recovery and an ERV for enthalpy recovery during humid summer days. They presented measurement results of the electric consumption of the two houses, one with an HRV, the other with an ERV related to the latent cooling load in residential air-conditioning. However, while these studies have measured the performance and control of ERVs in experimental test houses, there have been no studies on the heat exchange efficiency of ERVs in full-scale residential buildings under actual indoor and outdoor conditions. Furthermore, there is no comparative study of an ERV using fixed efficiency, which is conventionally used in performance evaluation and actual efficiency of ERVs from measured values under operating conditions.

In this study, the heat recovery efficiency of an ERV in actual weather conditions was estimated based on field measurements, and this estimate was used to analyze its heat recovery efficiency according to changes of outdoor and indoor conditions. The field measurements were taken in a full-scale multi-residential building over 20 days in winter. Then the characteristics of the sensible heat and latent heat exchange efficiency of the ERV were analyzed based on these measurements. In addition, variable heat recovery efficiency was deduced by field measurements, and the efficiency's effects on heating load and heating energy demand were analyzed using simulation methods.

2. Measurements

2.1. Field measurements

Field measurements were taken in Korea in winter over a period of 20 days from February 24, 2016 to March 14, 2016 to analyze the heat exchange performance of a ventilation system in actual indoor and outdoor conditions. The analyzed house was a full scale multi-residential house with a floor area of 84.0 m^2. The house was not occupied at the time the measurements were taken, but constant indoor temperature and humidity were maintained as per the standard test method for heat recovery ventilators [14]. A ventilator was installed in each room as shown in Fig. 1. Four ERV units and two natural ventilation units were implemented in the house. The ERV system, which has a cross-flow, membrane-based design, was placed in window frames and not connected to a duct, so it was free from duct-related problems, such as contaminants and pressure drops. The system could be operated separately in each room [21]. Membrane heat exchangers using a porous membrane as the heat and moisture transfer surface were incorporated into this ventilation system [22]. The natural ventilation units were not operational during the measurement period because of balanced flows between supply air and exhaust air. The specifications of the ERV system are shown in Table 1.

The analyzed space (shaded area) was limited to the living room and the kitchen/dining room. Air flow between rooms was eliminated by sealing off all the exits to adjoining rooms. The ERV system was operated only in the analyzed space, and no other ERV systems were operated during measurements. The measured variables were indoor and outdoor temperature and humidity. Portable data loggers (Testo175H1; -20 to $+55\,°C$, $\pm 0.4\,°C$; 0 to 100%, $\pm$ 2%RH, respectively) capable of simultaneously recording the temperature and relative humidity were installed at the ventilation supply air inlet and return air outlet. Air temperature and relative humidity in the center of the living room space were measured by the data loggers, and the outdoor air temperature and relative humidity were also recorded. The measurement interval was one minute. Specifications are given in Table 2.

To investigate the heat recovery performance under the heating conditions of a residential building, the indoor temperature ($22 \pm 0.3\,°C$) and relative humidity (40%) were controlled by a radiant heating system and two electric humidifiers (Novita NHU-5500s; 300 ml/hr), respectively, according to the Korean standard test method [14]. In the Korean standard test method, the outdoor air temperature and humidity are controlled at $2 \pm 0.2\,°C$ and 75.1% RH, respectively. However, our purpose in this study was to measure the heat exchange performance of the ventilation system under actual conditions, so the outdoor conditions were not controlled. Instead, we allowed the actual outdoor conditions.

2.2. Evaluation of the heat exchange performance

The heat or enthalpy exchange performance of ventilation systems can be calculated from the temperatures, humidity, and flow rate. According to ASHRAE Standard 84 [23], the effectiveness of the heat or enthalpy of a system can be expressed by the conditions of the supply air (SA), return air (RA), and outdoor air (OA) as follows:

$$\varepsilon = \frac{\dot{m}_s(x_1 - x_2)}{\dot{m}_{min}(x_1 - x_3)} \tag{1}$$

where, ε is the sensible or total effectiveness [–], x_1 is the OA temperature [°C] or enthalpy [kJ/kg], x_2 is the SA temperature [°C] or enthalpy [kJ/kg], x_3 is the RA temperature [°C] or enthalpy [kJ/kg], $\dot{m}_s$ is the supply air flow rate [m^3/h], and $\dot{m}_{min}$ is the lower of the exhaust or supply air flow rate [m^3/h]. The values of the two air flow rates were approximately equal for the ventilation system in this study. Assuming the same flow rate across the ventilation system, the sensible effectiveness can be expressed as

$$\varepsilon_s = \frac{T_{OA} - T_{SA}}{T_{OA} - T_{RA}} \times 100\ [\%] \tag{2}$$

and the latent effectiveness as

$$\varepsilon_l = \frac{W_{OA} - W_{SA}}{W_{OA} - W_{RA}} \times 100\ [\%] \tag{3}$$

and the total effectiveness as

$$\varepsilon_T = \frac{h_{OA} - h_{SA}}{h_{OA} - h_{RA}} \times 100\ [\%] \tag{4}$$

where ε_s is the sensible effectiveness, ε_l is the latent effectiveness, ε_T is the total effectiveness, T is the temperature of air, W is the