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Investigation on the performance of a heat recovery ventilator in different climate regions in China

Lingling Bao [a, b, *], Jinggang Wang [a, **], Hongxing Yang [b]

[a] School of Urban Construction, Hebei University of Engineering, Handan, China
[b] Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

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ABSTRACT

In recent years, haze becomes a choking problem in northern China in winter. A HRV (heat recovery ventilator) is an effective device to provide clean indoor environment by supplying fresh outdoor air to residential and commercial buildings, but the HRV system must be combined with an air filter to remove the fine particular matter of the outdoor air. There is limited information regarding this integrated system. This paper investigates the influences of an air filter on the performances of the HRV system in three modes by experiment and the application potential is also reported for this integrated system in five climate zones of China. The experimental results show that the integrated system can meet the required threshold value of 75 μg/m^3, but the installation of an air filter reduces the air flow rate and increases the power of the fan. Compared to the HRV system, the sensible heat efficiencies of the integrated system are increased; and the total sensible heat transfer capacities are slightly decreased in the three modes. The case study shows that in Harbin and Beijing, the integrated system can recover more energy than that in other three cities in winter.

1. Introduction

Buildings are equipped with HVAC (heating, ventilating, and air-conditioning) systems which are better insulated and tighter for less infiltration to decrease the energy consumption in winter in northern China. In order to meet the requirement of IAQ (indoor air quality), large quantity of fresh air has to be brought into the rooms which results in more energy consumption for heating and cooling fresh air. Applications of the ERV (energy recovery ventilator) and HRV (heat recovery ventilator) are effective solutions for this issue [1]. The ERV and HRV are widely used in some Europe countries [2,3], but not in China. The public building code in China issued in 2005 states that the HRV or ERV should be installed in HVAC systems [4]. The exhaust air passes through one side of the ventilator with counter flow passing through the other side of ventilator to bring fresh air from outdoor. In a HRV, sensible heat will be exchanged between the exhaust air and the fresh air through the heat transfer channels. In an ERV, both sensible and latent heat will be exchanged between them. Although the heat recovery efficiency of the ERV is higher than that of the HRV, the maintenance fee and the initial cost of the ERV are higher than that of the HRV [2,5]. Moreover, in an ERV the contaminants would be transferred from exhaust to supply air [6–8]. The problem of balancing energy conservation and cost is more complicated owning to different climates, indoor design conditions and heat exchange efficiency of the HRV or ERV, etc. [9] Zhang and Liu [10,11] propose that the ERV is suitable and recommended for hot and humid regions, while the HRV is more efficient in cold regions.

In recent years, air pollution becomes a choking problem in China, and the fine particular matter (PM2.5) in air is the critical pollutant [12] which plays an important role in human health problem [13,14] in northern China now. Wang [15] reported that in dry and cold winter in Beijing, the PM2.5 concentration of the outdoor air is higher than that in summer. In January 2013, the PM2.5 concentration of the outdoor air was increased to 500–800 μg/m^3 in Beijing [16] which greatly exceeds the current Chinese Ambient Quality Standards of 75 μg/m^3 for 24-h average [17]. Because of the poor outdoor air quality, the HRV alone is invalid for improving the IAQ of the indoor space by supplying the outdoor air to the room directly. A HEPA (high efficiency particular

* Corresponding author. School of Urban Construction, Hebei University of Engineering, Handan, China. Tel.: +86 310 8579070.
** Corresponding author. Tel.: +86 310 8579070.
E-mail addresses: lingling5934@163.com (L. Bao), jinggangwang@hebeu.edu.cn (J. Wang).

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Nomenclature

HRV	heat recovery ventilator
ERV	energy recovery ventilator
η_s	sensible heat efficiency
Q_s	sensible heat transfer capacity, kW
Q_h	fresh air sensible heating load, kW
G	air flow rate, kg/s
c_p	specific heat capacity at constant pressure, kJ/(kg °C)
t	temperature, °C
φ	relative humidity, %
$\dot{Q}_h$	accumulative fresh air sensible heating load, kWh
$\dot{Q}_s$	accumulative sensible heat recovery capacity, kWh
H	running hours of the HRV/integrated system, hr
C	concentration of PM2.5, μg/m^3
P	static pressure, Pa
v	air velocity, m/s

Subscripts

s	sensible
in	indoor
out	outdoor
1	inlet
2	outlet
τ	the τ^{th} hour

air) filter is necessary to be installed upstream of the HRV to clean the outdoor air. This paper is to investigate the effect of the air filter on the performance of the HRV.

Some studies have focused on the performances of the HEPA filter on PM2.5 mass concentrations. Spilak et al. [18] state that the particle filtration units can help reduce the PM2.5 concentrations by 54.5% in dwellings. Zaatari et al. [19] investigate the relationship among the filter pressure drop, the indoor air quality and energy consumption in the rooftop HVAC units. The result shows that choosing the right efficiency of filters is essential to ensure low-energy adoption and a healthy indoor environment. Marsik et al. [20] present a dynamic model for evaluating the indoor PM2.5 levels and energy consumption associated with ventilation. The result demonstrates that using a HRV with an additional filter can save about US$690 annually compared with using natural ventilation.

The integrated system of a HRV plus an air filter can solve two issues, i.e. energy saving and better IAQ in cold climate regions. On the one hand, a HRV of the integrated system could recover energy from the indoor exhaust air, and the filters could clean the polluted outdoor air, so that cleaner outdoor air can be supplied to the room space for improving the indoor air quality. The energy conservation capacity is dependent on the efficiency of the HRV and the parameters of both indoor and outdoor air [2]. On the other hand, compared with a HRV alone, the filters would increase the flow resistance and lower the flow rate of the integrated system which would result in higher energy consumption. The influence of an air filter on the performances of the HRV must be investigated.

In this paper, the resistance characteristics and sensible heat efficiency of both the HRV alone and the integrated system are investigated by experiment; the influence of the air filter on the performances of HRV is analyzed. Meanwhile, the sensible heat efficiency and the sensible heat transfer capacity of the two systems are compared. A typical residential apartment is an example, whose energy consumption and heat recovery of the integrated system are analyzed whether it is adoptable in different climate zones of China in winter.

2. Methodology

2.1. Experimental setup

In order to remove PM2.5 economically, a counter-cross flow sensible plate heat exchanger and an F7 air filter according to EU standard [21] are chosen for investigation in this project. The experimental system and test points are presented in Fig. 1. The specifications of each main component are listed in Table 1. The HRV has 3 possible air flux settings: "Min," "Norm" and "Max." The heat exchange element is VM1 type produced by Systemair AB in Sweden, and it is made of an alloy steel plate with the thickness of 0.3 mm. The channel width of heat exchange element is about 40 mm. The outdoor air can be cooled by an air cooler installed in the duct to simulate cold air outside. In order to simulate high concentrations of PM2.5 outdoor air, a solid particle disperser is necessary.

(a) Schematic diagram of the experimental facility.
(b) Photos of the experimental setups.

2.2. Instrumentation

The specifications of the instruments are listed above in Table 2. The dry bulb temperature and relative humidity at the inlets and outlets of the HRV were measured by the Onset HOBO data loggers (Model: U12-11, with accuracy ±0.35 °C, ±2.5%). The data were recorded automatically at every 30 s interval for heat transfer performance analysis. The air velocity of the inlet and outlet ducts connected to the HRV was measured by TSI VELOCICALC Plus Multi-Parameter Ventilation Meters (Model: 8386A, with accuracy ±0.015 m/s) for calculating the air flow rate. Two TSI DP-CALC air flow micro manometers (Model: 5825, with accuracy ±1 Pa) were located at inlet and outlet of the air filter to measure the pressure drop of the air filter. Two TSI DUSTTRAK Aerosol Particulate Monitors (Model: 5820, with accuracy ±0.001 mg/m^3) were installed at inlet and outlet of the air filter to measure its filtration performance. The power consumption of the HRV was measured instantaneously by an electric power measuring meter (Model: TM9, accuracy about ±0.1 W).

2.3. Experimental procedures

As shown in Fig. 2, the experimental investigation consists of two tests, i.e., HRV alone and HRV combined with an air filter (integrated system). Each test has three modes, i.e., min mode, norm mode and max mode. First, to investigate the air flux, power and sensible heat transfer performances of the HRV alone in three modes were investigated. Second, to investigate the air flux, power, filtration performance and sensible heat transfer performances of HRV alone in three modes were included. It should be noted that about four steady heat transfer processes which may take 160 min are necessary to be adopted in investigating the heat transfer performance to obtain a fitting curves for the sensible heat efficiency.