Experimental study on the net outdoor airflow ratio in supply air of membrane-based energy recovery ventilator

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Abstract. The total energy recovery ventilator for outdoor air handing plays an important role in reducing energy consumption of the ventilation system. At the same time, the cross infection between fresh air and return air is a direct threat to the safety of energy recovery components with the influence of COVID-19. Therefore, how to improve the total exchange effectiveness and net outdoor air flow ratio in supply air of the heat recovery system has become an urgent problem to be solved. In this study, the composite membrane was prepared by non-woven fabric, siloxaneamide and lithium chloride solution, which was used as the membrane for the heat and mass transfer between fresh air and return air. The variation of the selective permeability of the composite membrane was studied experimentally. The experimental results show that the highest permeance of the composite membrane for the water vapor permeability can reach until $32.5 \times 10^{-8} \text{kg/m}^2\text{s Pa}$. The net outdoor air flow ratio in supply air is 94% when the air volume is $550 \text{m}^3/\text{h}$. The heat exchange efficiency of the heat recovery device is 63.2% under the conditions of the dry and wet bulb temperatures of return air and outdoor air are $21.2 \degree \text{C}/12.9 \degree \text{C}$ and $2.3 \degree \text{C}/1.2 \degree \text{C}$, respectively.

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1 Introduction

With the improvement of indoor environment, building energy consumption rises continuously. Heating, ventilation and air conditioning occupied almost half of the building’s energy consumption [1]. Due to the significant enthalpy difference between outdoor and indoor air, a large portion of energy is consumed in the outdoor air handling units. On the other hand, with the outbreak of COVID-19, fresh air ventilation has become an important link related to the safety of the building environment, attracting the attention of scholars around the world [2]. Therefore, the energy consumption and safety of the outdoor air handling system have become the focus of scholars.

As a typical heat recovery equipment, membrane based heat exchanger shows high efficiency in sensible heat and latent heat recovery. Among them, the structure and selective permeability of the membrane are the key factors of device performance. The cellulose acetate asymmetric membrane was made by Zhang et al. [3], which has low permeance in dry air, and high permeance of water vapor. The wet process of membrane was carried out to make the asymmetric membrane with dense surface layer by Zhang et al. [4]. They found that the mass transfer resistance of porous layer is small, and the resistance of compact surface layer accounts for more than 50% of the total mass transfer resistance. Ahluwalia et al. [5] prepared a composite membrane that consists of a very thin perfluorosulfonic acid ionomer layer sandwiched between two expanded polytetrafluoroethylene microporous layers. The results indicated that the amount of water vapor transported increases with the increase of relative humidity of imported wet air and decreases with the decrease of relative humidity. Duc et al. [6] prepared a new composite membrane based on stainless steel scaffolds, hollow titanium dioxide, polyvinyl alcohol and lithium chloride solution. The experimental results indicated that the lithium chloride can greatly reduce the diffusion resistance of water vapor. Meanwhile, it can be observed that the composite membrane has a high water vapor diffusion rate with a higher content of lithium chloride and the lower temperature.

Neda et al. [7]. reviewed the membrane-based energy exchanger which is widely used in energy recovery system for building ventilation. The impacts of flow configurations, module geometries and structure of membrane on the latent heat recovery efficiency were explored in detail. Liang et al. [8] proposed an independent air dehumidification system with membrane-based total heat recovery. The effects of airflow rates, relative humidity and temperature on the air dehumidification rates and thermal coefficient were evaluated experimentally. The COP of novel system with total heat recovery can reach 6.8. A latent heat exchanger with hollow fiber composite membrane was investigated experimentally by Cho et al. [9]. They found that the membrane modules illustrated a moisture removal rates of 0.027-0.124g/s and 35.3%–82.7% latent effectiveness under various operating conditions.

In this study, an energy recovery component (ERC) with a novel membrane which consists of non-woven fabric, siloxaneamide and lithium chloride is built. The characteristics of water vapor permeance and thermal performance is investigated experimentally.

2 Experimental methodology

The experiment is carried out under winter condition in the experimental apparatus as shown in Fig. 1. The experimental setup is composed of two opened branches, namely, the exhaust air and outdoor air branch.

The air in the pipe is driven by a fan with maximum air volume of 500m³/h. In outdoor air branch, the temperature and humidity of the air are adjusted by the surface cooler and heater which can be measured by the temperature and humidity sensor with working range of -40-125°C and 0-100%RH, respectively. Maximum uncertainty associated with temperature and humidity transducers are ±0.4°C and ±3%RH. The cooling and heat quantity are supplied with the chiller and DC power unit, respectively. The maximum cooling and heat capacity of the chiller and DC power are 5.5kW and 4.8kW, respectively. Then, the air enters the energy recovery component, which is used to recover the sensible and latent heat of indoor air. After that, the air volume is measured by the device which is consists of static pressure chamber, flow nozzle, perforated panel and exhaust chamber. The differential pressure of static pressure chamber is measured with the help of differential gage with working range of 100Pa and accuracy of ±0.2% reading. In the exhaust air pipe, the temperature and humidity are adjusted by the heater, dehumidifier and humidifier. The dehumidification method used in this experiment is cooling dehumidification, and the cooling amount is supplied by the chiller. The humidification capacity of the humidifier is 4kg/h. Then the air in an indoor condition enters the energy recovery component to perform the heat and mass transfer with the outdoor air through the composite membrane exchanger.

Fig. 1. Schematic representation of the test facility

3 Equations and mathematics

The water vapor permeability (WVP) of composite membrane was measured by the water method [10], which can be calculated as follows:
\[ P_v = \frac{\Delta m}{At\Delta p} \]  
(1)

Where \( \Delta m \) is the mass variation of moisture permeable cup, \( A \) is the area of water vapor transmission, \( t \) is the measuring time, \( \Delta p \) is the pressure difference of water vapor.

The net outdoor airflow rate in supply air is tested by the direct test method [11], in which methylbenzene is used as the tracer gas. As shown in Fig.1, the tracer gas is released at measuring position 1. Then the concentrations of tracer gas are tested at the measuring positions 2 to 4. The net outdoor airflow rate in supply air is calculated as follows:

\[ \alpha = \frac{C_1 - C_3}{C_1 - C_2} \]  
(2)

Where \( C \) is the tracer gas concentration at the measuring position.

The heat exchange efficiency of the heat recovery device can be calculated as follows:

\[ \eta = \frac{h_2 - h_3}{h_2 - h_1} \]  
(3)

Where \( h \) is the enthalpy of the air for the different measuring position. The enthalpy can be obtained by looking up the enthalpy-humidity diagram according to the temperature and humidity of the air.

The uncertainties of the experimental results are estimated by the methods proposed by Moffat [12]. As the main parameters in the present experiments, the maximum uncertainty of water vapor permeability, net outdoor airflow rate and enthalpy efficiency are \( \pm 2.1\% \), \( \pm 3.6\% \) and \( 8.7\% \), respectively.

### 4 Result and discussion

The new membrane in this investigation is made of non-woven fabric, siloxaneamide and lithium chloride, which is used as a porous support layer, dense membrane layer, and hydrophilic modified layer. Then the performance of composite membranes in terms of water vapor permeability was tested. Based on the weight lost method, the weight of water vapor through the membrane was measured. The temperature on both sides of the membrane is 23 °C and the relative humidity is 50% and 100% respectively.

As shown in Fig.2, the weight of water in the measuring cup decreases with time. The total test time is 3 hours and the weight is measured every half hour. The highest water vapor permeability is \( 3.25 \times 10^{-8} \text{kg/m}^2\text{s·Pa} \). Compared with the commercial paper membrane, the water vapor permeability increases by more than ten times. The water vapor permeability also decreases with time. This is mainly due to the decrease of water in the measuring cup, and the air layer between the water surface and the membrane is thickened. The air resistance is an important part of the water vapor transmission resistance. With the increase of the air layer resistance, the water vapor transmission rate decreases gradually.

![Fig. 2. Relationship of WVP and time](image2)

The detection of tracer gas concentration is shown in Fig. 3. The methylbenzene is released at location 1 into the test system, and the concentration is about 1.2 mg/m³. At this time, the outdoor air volume and return air volume are 550 m³/h. Then the concentration of the tracer gas is detected at the measuring positions 3 and 4, respectively. According to formula 2, the tracer gas concentration of measuring position 2 is needed for the calculation of net outdoor airflow rate. However, measuring position 2 is located at the inlet of outdoor air, and its tracer gas concentration is extremely low, which can be ignored. According to the experimental data, the net outdoor airflow rate is 94% when the air volume is 550 m³/h.

![Fig. 3. Detection of tracer gas concentration](image3)
5 Conclusions

In this investigation, a novel composite membrane is proposed and applied in the outdoor air ERC. The performance of membrane and ERC are studied experimentally. The following conclusions can be derived from the experimental results and analysis:

(1) This composite membrane has high WVP, which is much higher than that of the commercial paper membrane. The resistance of the air layer between the water surface and the membrane has a great effect on the WVP.

(2) With the increase of air volume, the enthalpy efficiency is decreasing. Increase the interaction time between water vapor and membrane is helpful for the increase of the latent efficiency and sensible efficiency.

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