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Contaminant transfer in run-around membrane energy exchangers

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ABSTRACT

The run-around membrane energy exchanger (RAMEE) is a novel membrane-based energy recovery system, which uses liquid desiccant to transfer heat and moisture between air streams. VOCs may transfer from the exhaust air to supply air due to (i) air leakage and (ii) dissolution of VOCs into liquid desiccant in the exhaust exchanger and subsequent evaporation into air stream in the supply exchanger. Experimental tests were conducted at different operating conditions using two RAMEE prototypes. Sulfur hexafluoride (SF_6) was used as tracer gas to test air leakage, and toluene (C_7H_8) and formaldehyde (HCHO) were used to test VOC transfer fraction. Results show that the exhaust air transfer ratio (EATR) of SF_6 was 0.0 ± 3.6% for both prototypes, which means the air leakage is negligible. The transfer of C_7H_8 was 2.3–3.4 ± 3.5%, while the transfer of HCHO was 4.5–6.4 ± 3.6% in the prototypes. It implies that there is a negligible transfer of low water soluble VOCs (i.e. C_7H_8), but possibly a small detectable transfer of very water soluble VOCs (i.e. HCHO) between the exhaust and supply air streams in RAMEEs. Moreover, the EATR values for both prototypes were insensitive to changes in air flow rate, liquid desiccant flow rate, latent effectiveness and environmental conditions.

1. Introduction

In cold and moderate climate countries, people spend up to 90% of their time indoors [1]. People are exposed to various contaminants present in indoor air during the time. There are several sources of indoor air contaminants in buildings which include building materials, furnishing materials, consumer products, equipment, indoor activities, and ventilation systems [2]. Among indoor contaminants, volatile organic compounds (VOCs) have attracted considerable attention in nonindustrial environments as many of them have adverse health effects on occupants (e.g. causing headache, drowsiness and difficulties in breathing, etc.). Above certain threshold concentrations, they are either known or suspected, to cause allergic, carcinogenic, neurotoxic, immunotoxic and irritant reactions among people [3]. More than 307 compounds of VOCs have been identified in indoor air in different countries [4]. Each compound seldom exceeds a concentration level of 50 $\mu g/m^3$, which is 100 to 1000 times lower than relevant occupational health threshold limit values (TLVs) listed by the American Conference of Governmental Industrial Hygienists [5]. The total concentration of all VOCs in non-industrial environments is normally well below 1 mg/m^3 [6]. Several researchers have studied the effects of VOC exposure on human health under a variety of design conditions [7–12]. Experimenters reported that there was no discomfort or irritation at total VOC concentration below 0.2 mg/m^3. Irritation of the eyes, nose and mouth was observed at total VOC concentration from 3 to 25 mg/m^3. Air quality was found to be substantially reduced causing headache and neurotoxic effects above 25 mg/m^3 or 0.02% of the air mass total VOC concentration.

Ventilation is the primary method for controlling air quality in the buildings as it brings in fresh air to dilute the contaminants. This can provide a healthy environment for building occupants and reduces the risk of contracting air transmitted diseases. Fresh air also plays an important role in worker productivity [13,14]. However, a substantial energy is consumed to condition the supply fresh air to comfort conditions. Up to 50% of the energy consumed in a building is used to condition fresh air supply [15]. The recent emphasis on energy conservation has led to the application of air-to-air energy recovery ventilators (ERVs) in building HVAC systems, as shown in Fig. 1. Depending on the outdoor conditions, the ERV heats and humidifies or cools and dehumidifies the fresh air, and reduces the heating or cooling energy consumption of the HVAC system.

Effectiveness (ε) and the exhaust air transfer ratio (EATR) [16] are two important properties of ERVs. Effectiveness provides an indication of the amount of energy recovered or transferred by the energy recovery system for a given operating condition. The EATR

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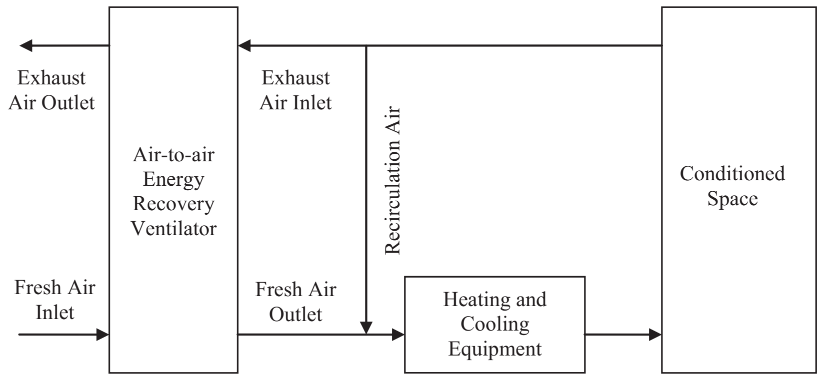

Fig. 1. Schematic of a typical HVAC system with an air-to-air energy recovery system.

is defined as the ratio of the mean concentration difference in the supply air divided by maximum bulk mean concentration difference between the exhaust and supply air inlets. These two indexes are calculated using Eqs. (1) and (2) [16] when the ERVs operate under balanced (equal) air flows.

$$\varepsilon = \frac{q_{\text{actual}}}{q_{\text{maximum}}} = \frac{X_{Sup.in} - X_{Sup,out}}{X_{Sup,in} - X_{Exh,in}} \quad (1)$$

$$EATR = \frac{C_{Sup,out} - C_{Sup,in}}{C_{Exh,in} - C_{Sup,in}} \quad (2)$$

where X is the dry bulb temperature (°C) for sensible effectiveness, humidity ratio (kg_w/kg_{da}) for latent effectiveness, and enthalpy (J/kg) for total effectiveness. C represents the airborne contaminant concentration (ppm).

Currently, there are several types of air-to-air energy recovery ventilators commercially available, as shown in Fig. 2 [17]. Some indoor generated contaminants may transfer through air-to-air ERVs from the exhaust air to the supply air along with the transfer of heat and moisture. This reduces the HVAC system's effectiveness for control of the concentration of indoor contaminants. Table 1 shows the comparison of sensible effectiveness, latent effectiveness, total effectiveness, and EATR values for different kinds of air-to-air ERVs [18].

The transfer mechanism for contaminant transfer varies with the type of ERV. Contaminant transfer in ERVs may happen due to air leakage between the air streams, carry-over in rotating parts of the energy recovery device or sorption of contaminants on regenerative exchanger surfaces or liquids [19]. Table 2 shows the comparison of the transfer mechanism of contaminants and the detailed transfer fraction of contaminants in different ERVs [20–23]. It was also found that various operating parameters may impact the contaminant transfer fraction. In the heat wheel, when the air flow rate increased from 3000 m^3/h to 3500 m^3/h, the transfer fraction of N_2O increased by 10–20%. In addition, N_2O transfer fraction increased by 4 times when the rotational speed of the wheel increased from 2 to 8 rpm [22]. However, EATR was very low (less than 0.3%) in all cases.

The run-around membrane energy exchanger (RAMEE) system is a novel energy recovery system, which mainly consists of two liquid-to-air membrane energy exchangers (LAMEEs), as shown in Fig. 3 [24]. The exchangers are made using a semi-permeable

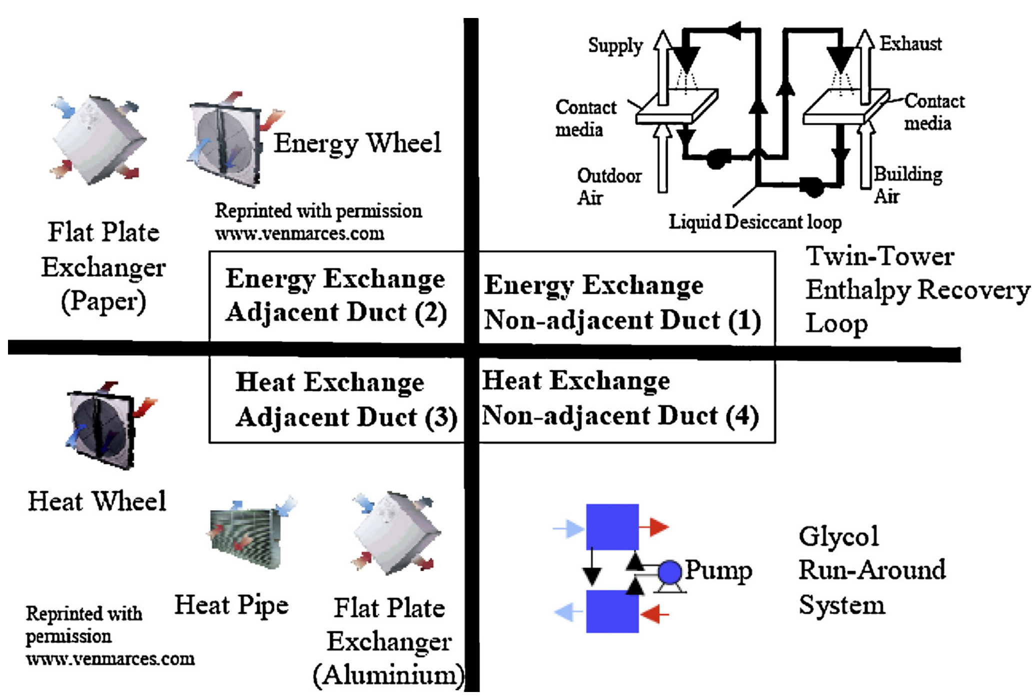

Fig. 2. Four main categories of existing air-to-air energy recovery systems [17].