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Formaldehyde transfer in residential energy recovery ventilators

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ABSTRACT

The rotary enthalpy wheel design used in many energy recovery ventilators (ERVs) is designed to transfer heat and moisture between supply and exhaust air streams. The wheel, however, can also transfer formaldehyde and other indoor contaminants from the exhaust stream to the supply stream through air leakage, entrainment in the porous wheel, and adsorption/desorption to the filter medium. This contaminant transfer reduces the benefit of the mechanical ventilation provided by the device. Field and chamber experiments were used to quantify the formaldehyde transfer efficacy (the fraction of formaldehyde transferred from the exhaust stream to the supply stream) in a common ERV model under varied conditions. In field experiments, the transfer efficacy was approximately 29%. Chamber tests showed formaldehyde transfer efficacy between 10 and 29%. The bulk of the transfer was due to air leakage and entrainment within the wheel, with up to 30% of the transfer attributed adsorption/desorption from the filter medium. The transfer efficacy decreased with increasing air exchange rate and supply air temperature. The transfer efficacy increased as the supply and exhaust streams were unbalanced in flow rate. Overall, the air leakage through the device substantially exceeded the product rating of 10%, with 27–28% air leakage measured in field experiments and 12–19% air leakage in chamber experiments.

1. Introduction

Mechanical ventilation systems were once considered unnecessary for single-family, US homes because the homes were thought to be leaky enough to provide sufficient ventilation. However, new demand in residential construction for new energy-efficient homes with greater air tightness has made mechanical ventilation a necessary design consideration. Today, one commonly used ventilation system is the energy recovery ventilator (ERV), selected for its system efficiency and ability to deal with both sensible and latent loads. ERV systems are typically operated as balanced ventilation systems: the system has a supply fan and an exhaust fan that are equally sized so they move a similar air flow rate to minimize the pressure difference between indoors and outdoors. In some cases, indoor pressure may be increased to prevent infiltration of outdoor pollutants. Some new ERV systems include filtration media such as high MERV rating filters and pre-filtration for large particles to improve indoor air quality. Shurcliff [1] provides an overview of residential air-to-air heat exchangers, and La et al. [2] provide detailed review of rotary desiccant technology.

Typically, ERV systems contain a rotary enthalpy wheel (REW) that is axially placed against the air streams and rotates between both supply and exhaust air streams as shown in Fig. 1. The enthalpy device works in two ways that account for seasonal variation. During cooling days, the wheel removes heat and moisture from the supply airstream (outdoor air) and discharges them to the exhaust air stream. During heating days, the wheel absorbs heat and moisture from exhaust air stream and transfers it to preheat and humidify the incoming cold and dry air from outside.

Concerns have been raised that some indoor-generated pollutants may be transferred through the same mechanisms as heat and moisture, thus compromising the pollutant removal efficacy of this ventilation system. The transfer efficacy through the ERV filter media can be defined for formaldehyde:

$$FTE = (F_{S,out} - F_{S,in})/(F_{E,out} - F_{S,in}) \quad (1)$$

where $F_{S,out}$ and $F_{S,in}$ are the formaldehyde concentrations in flows out and into the ERV, and $F_{E,in}$ and $F_{E,out}$ are the concentrations in exhaust flows out of and into the ERV, assuming flow rates are balanced. If exhaust and supply flow rates are not balanced, the ratio above must be multiplied by the ratio of supply to exhaust flow rates. This is the overall transfer efficacy via all transfer mechanisms, and the formaldehyde transfer efficacy will be

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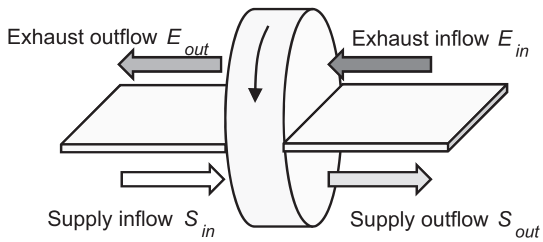

Fig. 1. Schematic of exhaust and supply flows through a rotary enthalpy wheel.

referred to as the FTE. Ideally, ERVs have a high transfer efficacy of heat and moisture and a low transfer efficacy of contaminants.

The exhaust air transfer efficacy (EATE), is the fraction of exhaust air that is transferred to the supply air stream. Here, this was calculated:

$$EATE = (C_{S,out} - C_{S,in})/(C_{E,out} - C_{S,in}) \quad (2)$$

where C is the CO_2 or tracer gas concentration in each of the air streams. Again, for unbalanced flows, the ratio above must be multiplied by the ratio of supply to exhaust flow rates. Because the indoor and outdoor concentrations of CO_2 differed significantly in the field tests, the concentration of this gas was used to assess transfer between supply and exhaust air streams. The EATE includes transfer via air leakage and air entrained from within the wheel but does not include adsorption/desorption effects, as the sorption of CO_2 and the tracer gas onto the filter medium is expected to be negligible. Leakage occurs through small openings or gaps that exist between the compartments of the opposing air streams and the aluminum frame around the REW. Roulet et al. [3] found air transfer efficacy between 5 and 26% for three rotary ERV models, with widely varying transfer efficacy for different VOCs.

Patel et al. [4] provide an overview of contaminant transport through different types of heat recovery ventilation systems. One alternative to the rotary wheel design for air to air heat exchangers is the parallel-plate total heat exchanger [5]. These can be constructed using a range of membrane materials, and Zhang et al. [6] reported that the permeability of membrane materials to volatile organic compounds (VOCs) can vary over three orders of magnitude depending on the material. However, materials tested that were very permeable to water (desirable) tended to select more for water vapor than for the 5 VOCs tested, and the materials that were highly permeable to VOCs were not very permeable to moisture. Thus, it is not expected that the transfer efficacy of formaldehyde through membranes will vary widely in practice provided that membrane materials selected are favorable for moisture transfer. Similarly, the desiccant material in rotary wheel systems can also be designed to have higher selectivity for moisture than VOCs [7].

A particular concern with rotary enthalpy wheels is that formaldehyde—a highly water-soluble compound with similar chemical properties to water—can be easily adsorb onto the filter media from exhaust air and subsequently desorb when the wheel encounters the opposing supply air stream. Formaldehyde may also be transferred due to re-entrainment of air trapped within the wheel or via direct air leakage paths around the wheel.

Formaldehyde health effects at low concentrations are well documented. This compound is an irritant to the mucous membranes [8], was listed as a known human carcinogen by the National Toxicology Program [9] and has been associated with childhood asthma [10]. Based on health impacts, formaldehyde has been identified as one of the priority pollutants of concern in residences [11]. Given the health risks associated with formaldehyde exposure, it is important to ensure that the use of ERV systems—in particular the REW for energy efficiency—does not lead to poor indoor air quality that offsets the advantages of introducing mechanical ventilation in the first place.

While studies have demonstrated that ventilation using ERVs can decrease indoor formaldehyde concentrations [12,13], the body of research on the transfer of formaldehyde through ERVs themselves is limited. Typically, a tracer gas is used to determine the transfer efficacy via air leakage and entrainment of air within the wheel, whereas formaldehyde is measured to determine transfer via adsorption/desorption as well as air leakage and entrainment. Fisk et al. [14] found that the transfer efficacy of formaldehyde was 7–15% through a rotary wheel enthalpy exchanger, with 5–8% transfer of tracer gases. Similarly, Andersson et al. [15] reported a transfer efficacy of 1–9% for rotary wheel heat exchangers installed in commercial buildings in Sweden. While the basic design of the rotary wheel ERV remains the same, the filter material in newer models have been redesigned to optimize heat and moisture transfer. Contaminants can be purged from a silica-gel rotary wheel, such as those used in air-cleaning devices, by heating the airstream used for purging, however the power required exceeds the energy benefit from the latent heat transfer (e.g. [16],). In the run-around design tested by Patel et al. [4] that uses a liquid desiccant to transfer heat and moisture between two air streams, air exchange was negligible and formaldehyde transfer was 4–6%.

The thickness of the REW medium in ERV systems is typically 2.5–4.0 cm to ensure optimal periodic storage of heat and moisture as each portion of the REW constantly switches between the air streams. The transfer rate between supply and exhaust streams tends to increase with the thickness of the wheel because of the increased volume of air entrained in the wheel. Slower wheel revolution can further increase the efficacy of energy recovery as well as contaminant transfer between supply and exhaust streams by increasing the contact period between the wheel medium and each air stream during each revolution.

This study investigates the formaldehyde transfer efficiency for one ERV system with a REW as well as the fractions of transfer attributed to adsorption/desorption versus air leakage and entrainment. Although contaminant transfer through ERVs has been studied previously, these studies were completed 20 or more years ago. Given recent increased market uptake of ERVs, the reduction of ventilation effectiveness by contaminant transport warrants reconsideration, using a current model under installed conditions. According to the product specifications, the exhaust air transfer efficacy (EATE) of the unit is approximately 10% at 50 and 100 Pa static pressure drop across the medium, at maximum rated air flow. The purpose of this study is to assess whether significant formaldehyde can be transferred through a common US ERV model, and what the dominant mechanisms for the transfer are. Because this model is commonly used, formaldehyde transfer through an installed unit could have significant implications for ERV effectiveness in the US. In this study, measurements taken in a full-scale house were supplemented by chamber experiments to study the formaldehyde transfer efficacy is affected by ventilation rate, balanced vs. unbalanced flow rate, and outdoor air temperature. In the next section, the study design to investigate the formaldehyde transfer via these mechanisms is presented, with the experiments divided into two stages. Finally, results and discussion are presented.

2. Methods

2.1. ERV test unit and rotary enthalpy wheel

The ERV unit used in the field and chamber experiments is equipped with two brushless variable speed fans—one for supply