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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.

Key words: energy recovery ventilator, formaldehyde, indoor air quality

Highlights:

- 28-29% of formaldehyde was transferred from exhaust to supply in an installed ERV
- In chamber tests the formaldehyde transfer efficacy was 10 to 29%
- Air leakage dominated transfer, with adsorption to filter medium also contributed
- Device rating of 10% air leakage was significantly exceeded in field tests (27-28%)

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 Figure 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 pre-heat and humidify the incoming cold and dry air from outside.

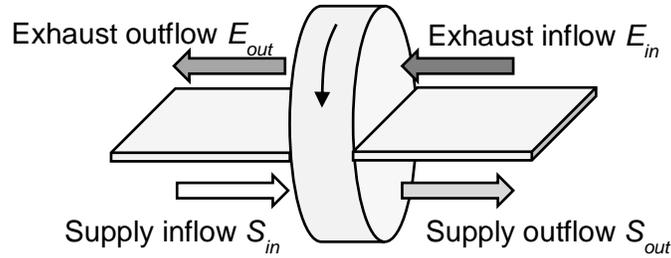


Figure 1 Schematic of exhaust and supply flows through a rotary enthalpy wheel.

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 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 CO₂ 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 CO₂ 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 to 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 air and another for exhaust—with an overall rated air flow of 120-340 m³ h⁻¹. It is recognized as one of the most energy efficient systems, requiring only 40 watts to deliver 120 m³ h⁻¹ of air. The manufacturer information sheet stated that the system has a built-in sensor, which automatically balances the supply and exhaust air streams through the unit. The product performance specification lists a sensible recovery efficiency of approximately 80% and a moisture transfer ratio of 0.55 at maximum flow rate (340 m³ h⁻¹) during heating season.

The heat exchanger of the ERV system is a cylindrical wheel comprised of six replaceable and washable filter pies/ wedges. The filter media is a hygroscopic 3cm-thick random matrix polymer which in addition to transferring energy, also functions as a MERV 12 filter that is 95% effective in removing particles as small as 1.8 microns. Each filter pie is made of synthetic fibers impregnated with desiccant substrate. The REW rotates at a fixed speed of 30 rpm. At any one time, a constant and equal fraction of the surface is facing partially the supply and exhaust air streams. As the wheel rotates, thermal energy is stored in the media as the warmer, more humid exhaust air passes through, and when the same section of the wheel encounters incoming outdoor air in the counter-flow direction, the media releases the thermal energy to the cold and dry air. The wheel revolution of this system is not adjustable, which limits the ability to transfer heat from exhaust air particularly when outdoor temperature becomes very low.

Initially, a preliminary investigation was carried out in a new home equipped with an ERV. Experiments were later performed in the environmental chambers at Lawrence Berkeley National Laboratory using an ERV unit of the same model and size. The facilities are small (19 m³) to medium (50 m³) scale chambers equipped with thermal and ventilation controls. The larger chamber used for Stage 2 is constructed from wood materials with painted surface.

2.2 Field study

In the first stage, an installed unit of the ERV model was tested in a new, uninhabited and unoccupied home. This home in Pittsburgh, PA serves as a test house for building sciences experiments and is H1 in Willem et al. [17] and Hult et al. [13]. Measurements were taken between June and August 2011, at which point the home was two years old. It was a 190 m² two-story house with four bedrooms built with low-emitting construction materials (with the exception of carpets). However, the concentration of formaldehyde measured without operating mechanical ventilation was 62 µg m⁻³, which is higher than typical for new homes constructed with low-emitting materials [13]. Although the home was unoccupied, it was fully furnished, so both furnishings and conventional carpet may have contributed to elevated formaldehyde emission. The home was well sealed: the measured air changes per hour at 50 Pa pressure difference (ACH50) was 1.20. An ERV unit with maximum rated flow rate of 340 m³ h⁻¹ was installed in the home. The home had centralized thermal control and during the study, the air temperature was set at 22.2 °C.

The ventilation system was manipulated to achieve three distinct ventilation settings. Each setting was maintained for two weeks and perfluorocarbon tracer (PFT) techniques were used to measure the air exchange rate in the home during each period [17]. The measured air exchange rates were 0.19, 0.24, and 0.43 h⁻¹. To establish air exchange rates at each setting, air samples were collected at two indoor locations and one outdoor location. The resulting PFT concentrations as well as PFT emission rates were used to calculate the air exchange rate, using the outdoor concentration as the background level.

In the ERV testing, air samples were collected at four locations: upstream and downstream of the supply and exhaust air. The sampling locations were approximately 30-40 cm from the ERV unit. Duplicate samples were collected at random sampling locations during each sampling session. Samples were collected on silica gel cartridges coated with 2,4-dinitrophenylhydrazine (DNPH XPoSure Aldehyde Sampler; Waters corporation) without ozone scrubbers. Air sampling was performed using a multichannel peristaltic pump, with a sampling flow rate of 1L min⁻¹ and sampling duration of 20 minutes. The flow rate was measured and recorded once before and once after the sampling and the average was used in the calculation of the concentration of formaldehyde. Ambient carbon dioxide was also measured at each of the sampling locations in order to determine the air transfer efficacy (EATE) between exhaust and supply streams of the ERV.

Air samples were analyzed for formaldehyde and acetaldehyde following ASTM Standard Method D 5197-09e1 [18]. Each sampling cartridge was extracted into 2 mL of high purity acetonitrile. Sample extracts were analyzed using high-performance liquid chromatography (HPLC; 1200 Series; Agilent Technologies) with UV detection at 360 nm and a C₁₈ reverse phase column with 65:35 H₂O: acetonitrile mobile phase at 0.35 ml min⁻¹. Analytes were quantified from multi-point calibrations of external standard mixtures. All samples were above the quantification limits.

2.3 Chamber experiments

The objectives of the chamber experiments were three fold: 1) To confirm the outcomes of field measurements, 2) To investigate the relative contributions of transfer from adsorption/desorption to the filter material and air leakage paths, and 3) To understand the influence of other factors that impact formaldehyde transfer rate such as air temperature. In the chamber experiments, formaldehyde-loaded air was passed through an ERV unit of the same model installed in a 50m³ chamber. For comparison to formaldehyde, sulfur hexafluoride (SF₆) was used to determine the transfer rate through system air leakage paths. We simulated the conditions in the Stage 1 field study by varying airflow rates for balanced and unbalanced conditions. We set the flow rates at three settings: 85±5, 175±3, and 350±8 m³ h⁻¹. The supply and exhaust air flow rates were carefully balanced and the same air pressures at both inflows of the REW were maintained.

We then varied the supply air temperature to simulate ERV operation in different climatic regions. While the flow rate was maintained and balanced at the maximum rated flow rate for the ERV ($350 \text{ m}^3 \text{ h}^{-1}$), experiments were conducted with outside (supply) air temperatures of 4, 18 and 30°C . The relative humidity was between 42 and 48%. This temperature experiment was then repeated at a flow rate of $220 \text{ m}^3 \text{ h}^{-1}$. The conditions were selected to represent typical outdoor temperatures during various seasons.

In addition to the ERV unit and the environmental chambers, the experimental set-up was comprised of three main systems that were used for different functions: 1. Controlling and monitoring of thermal conditions and air flow rates, 2. Injecting formaldehyde and SF_6 at desired rates, and 3. Air sampling and analysis. The ERV system was connected to the chamber using a combination of rigid and flexible ducts. The testing facility was located inside a building with centralized heating and cooling systems. The temperature inside the experimental chamber was maintained close to the building thermal conditions. To achieve a typical hot or cold outdoor air temperature, several room heating devices or cold traps were connected to the upstream flow of supply air. In order to regulate and balance the air flow rate, four iris duct dampers were installed, one at each connecting point between the ERV and the ducts. Air temperature, RH, and pressures were monitored continuously at 30 second intervals throughout each experiment with an Automated Performance Testing System (APTS) equipped with sensors and operated with data logging software (The Energy Conservatory, Minneapolis, MN). The APTS and the sensors were calibrated by the manufacturer prior to the study. The pressure difference across each damper was measured before each experimental setting and air flow rates were balanced and unbalanced to achieve flow conditions characteristic of operational conditions. Pressure measurements have a resolution of 0.1 Pa. The temperature sensor has an accuracy of $\pm 0.25^\circ\text{C}$, and the RH sensor has an accuracy of $\pm 5\%$ of the value.

As a formaldehyde source, diluted liquid formalin was injected into the chamber using a 10mL glass syringe pump (Model 975, Harvard Apparatus, South Natick, MA). The injection rate was set to produce a formaldehyde concentration of $60\text{-}75 \mu\text{g m}^{-3}$ in the chamber. The syringe pump was connected to a tube that delivered the mixture to the surface of a heated plate in order to quickly evaporate the liquid. The air above the plate was ventilated with a low-speed, oscillating fan. SF_6 gas from a standard cylinder was transferred into a 10 L bag. This bag was then connected to a peristaltic pump to draw pure SF_6 continuously into the room at a constant rate to achieve the desired concentration.

After changing settings, researchers waited at least 24 hours before taking samples to allow steady-state conditions to establish. Sampling points for the upstream and downstream supply and exhaust air were located within the ducts, about 50 cm from the ERV unit. An additional sampling point was located in the chamber. Measurements were collected at all five points simultaneously. Integrated formaldehyde samples were obtained using DNPH-coated silica samplers (Waters) at a rate of 1 L min^{-1} using four peristaltic pumps for a period of 40 minutes. The flow through the sampler was measured using a primary air flow calibrator (Gilibator) with a precision greater than 2%.

Formaldehyde samples were analyzed following the same method as in Stage 1. Grab samples to determine SF_6 concentration were collected into 0.5 L Cali-5-BondTM sampling bags using peristaltic pumps. SF_6 samples were subsequently analyzed using the GC-ECD system. The SF_6 concentrations detected were in the range of about 20 to $1200 \mu\text{g m}^{-3}$ with an accuracy of approximately 2%.

2.4 Uncertainty in transfer efficacy

The uncertainty in transfer efficacy quantities can be estimated using error propagation methods. Formaldehyde measurements from previous studies taken following a similar protocol had uncertainty of 4%, based on repeated samples [17]. Assuming 4% uncertainty in the formaldehyde measurements, the uncertainty in the FTE is

$$u(\text{FTE}) = 0.04 * (F_{S,\text{out}} + F_{S,\text{in}}) / (F_{S,\text{out}} - F_{S,\text{in}}) + 0.04 * (F_{E,\text{out}} + F_{S,\text{in}}) / (F_{E,\text{out}} - F_{S,\text{in}}) \quad (3)$$

Thus, for the field experiments, uncertainty in the FTE is approximately 3 percentage points, using the data listed in Table 1, and the uncertainty in the FTE for chamber experiments is expected to be comparable.

3. RESULTS & DISCUSSION

We hypothesized that ERV unit with REW would transfer some amount of formaldehyde from the exhaust air stream to the supply air stream following some mechanisms and the rate of transfer would depend on various factors such as flow rates, wheel revolution rates, air flow balance, and environmental conditions. Our results, although limited to one ERV system, suggest that an ERV with an REW could transfer formaldehyde at a rate that is not negligible.

3.1 Field study results

Table 1: Test conditions, measured concentrations and transfer rates for Stage 1 field experiments.

Flow rate [m ³ h ⁻¹]		Indoor conditions		Outdoor conditions		Measured formaldehyde concentration [μg m ⁻³]				Transfer efficacy [%]		
Supply	Exhaust	T (°C)	RH (%)	T (°C)	RH (%)	Supply inflow	Supply outflow	Exhaust inflow	Exhaust outflow	HCHO	Air	Moisture
50	85	24	45	25	46	7.8	28	49	37	29	27	44
95	145	25	50	25	61	4.6	23	46	33	29	27	45
505	660	24	43	23	54	4.0	17	39	28	28	28	45

Field results showed the formaldehyde transfer efficacy was 28-29% through the ERV system. Table 1 shows the experimental conditions, measured formaldehyde concentrations, and the transfer rates of formaldehyde at three ventilation rates. When the air flow rate through the system was increased, the transfer efficacy of formaldehyde decreased, but the transfer of moisture, which can be beneficial, also decreased. Nevertheless, the formaldehyde transfer efficacy of approximately 29% under normal operation of the ventilation system is at the high end of previous results. Carbon dioxide concentrations sampled at the same locations as formaldehyde were used to calculate the air transfer efficacy as indicator of leakage in the system. The results indicate that about 27% of exhaust air was transferred to the supply stream at each of the three ventilation settings. It is clear that the supply and exhaust flow rates were not precisely balanced. Exhaust air flow rates were 25-40% higher than supply flow rates which may have contributed to the substantial air transfer efficacy between exhaust and supply air compartments. Air transfer is thought to be primarily due to air leakage between the supply and exhaust chambers in the ERV, although air entrained within the wheel can also contribute to this quantity. Since the FTE is the total formaldehyde transfer, and the EATE represents transfer (of air as well as contaminants such as formaldehyde) just through air transfer (leakage and entrainment), we can divide the EATE by the FTE to find the fraction of transfer due to air transfer. In this field experiment, air transfer may account for 92-100% of formaldehyde transfer in the ERV.

3.2 Impact of air flow rate and supply air temperature on FTE

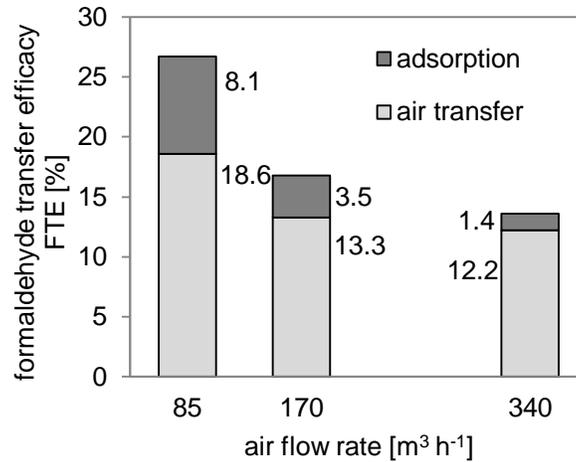


Figure 2 Formaldehyde transfer efficacy as a function of air flow rate from formaldehyde and tracer gas measurements in Stage 2 chamber experiments. Flow rates were balanced in these tests, air temperature was held at 18°C .

Figure 2 shows the formaldehyde transfer efficacy at three well-balanced air flow rates from ERV tests in the experimental chamber. Again, ‘air transfer’ includes air leakage and entrainment, whereas the ‘adsorption’ component refers to adsorption and desorption of formaldehyde from the filter medium. The adsorption/desorption component was calculated as the difference between the FTE and the EATE. As the ventilation rate was increased, the fraction of formaldehyde transferred tended to decrease, as did the components from air transfer and filter medium adsorption. The ERV model specifications listed the EATE to be 10%, but observed air transfer rates were higher: only at the maximum rated flow did the measured EATE of 12.2% approach the product specification. Formaldehyde transfer due to direct air transfer (leakage and entrainment) was substantially higher than the transfer attributed to filter media adsorption. The relative contribution of adsorption, however, increased as the air flow rate was lowered: from 10% of the total transfer at 340 m³ h⁻¹ to 30% at 85 m³ h⁻¹. Lowering the air flow rate increases the residence time of formaldehyde-loaded air in the filter media which may have led to increased transfer via adsorption/desorption. The FTE is somewhat lower than measured in the field experiment, which could be due to either device-to-device variation or installation practices.

If however, the air leakage through the unit were reduced through either improved design or installation procedures, the percentage of the transfer associated with adsorption to the filter would increase. As ERV units are improved, this transfer mechanism would need to be addressed in order to minimize formaldehyde transfer through the device.

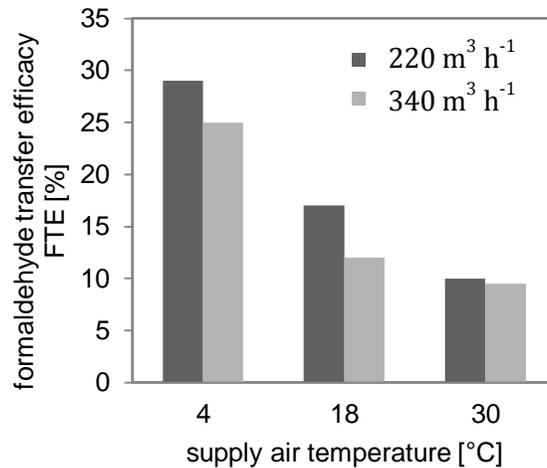


Figure 3 Impact of outdoor (supply) air temperature on formaldehyde transfer efficacy from Stage 2 chamber experiments. The temperature inside the chamber was held at 18°C.

Figure 3 shows the impact of supply air temperature on formaldehyde transfer efficacy in experimental chamber tests. The results show that the FTE decreased when the outside air temperature was increased. When the temperature was decreased from 18°C to 4°C, there was an increase of 12 percentage points in the FTE at both air flow rates. On the contrary, the change in FTE was substantially smaller as the outside air temperature was increased from 18°C to 30°C. The temperature difference between supply and exhaust air streams may drive air exchange between the streams. But if this effect were dominant, then the FTE would be minimum when the supply temp is 18°C because supply and exhaust air streams were most similar, but this was not the case. Given that formaldehyde emission from materials has been shown to increase approximately 11% per °C [19], it is not surprising that the FTE is temperature dependent. If increasing the temperature increases the rate at which formaldehyde is transferred between the air stream and the filter medium, then more of the substance would be transferred from the loaded filter segment to the exhaust stream during each revolution, thus increasing the adsorption portion of the FTE. Although it is expected that relative humidity would also affect the formaldehyde transfer efficacy [19, 20], relative humidity was not systematically varied in this study.

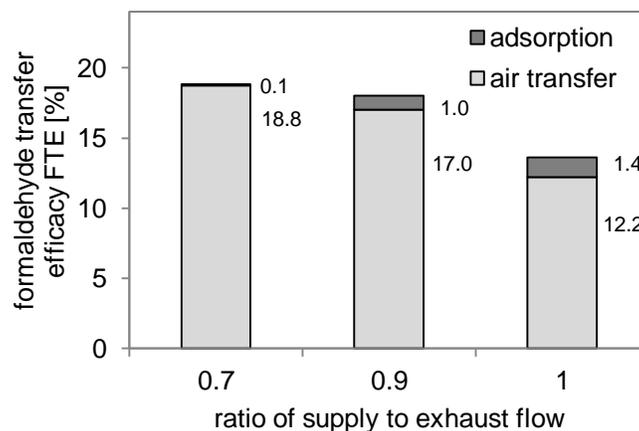


Figure 4 Impact of flow balancing on FTE from Stage 2 chamber experiment results. The supply flow was held at approximately 340 m³ h⁻¹ in each case. Air temperature was held at 18°C.

Chamber experiments were also performed to assess the impact of balancing supply and exhaust flows through the ERV, as shown in Figure 4. The ratio of supply to exhaust flows was reduced to 0.9 and 0.7 to simulate conditions in the field experiments. While the formaldehyde transfer efficacy was 13.6% for balanced supply and exhaust flow rates, the FTE increased to 18-19% as the exhaust flow was increased relative to the supply flow.

The results of 1-9% FTE reported by Andersson et al. [15] were for conditions where the supply duct at higher pressure than the exhaust. But Andersson et al. reported that when the pressure in the exhaust duct exceeded that in the supply, the FTE was as high as 50% for the specific ERV they were testing. Additionally, as the flows became more severely unbalanced, the portion of formaldehyde transfer associated with adsorption/desorption became negligible. Although unbalancing the flows did increase the formaldehyde transfer efficacy, these chamber experiment results were still significantly lower than the FTE reported in the field tests using the same ERV with similarly unbalanced flows.

4. Summary

Formaldehyde transfer through an ERV via air transfer and adsorption/desorption from the filter medium was explored using field and chamber experiments. Chamber experiments indicate that transfer is primarily through air transfer (either leakage between the supply and exhaust chambers or transfer of air entrained in the porous wheel medium). The chamber experiments also show that the FTE decreased as air flow rate was increased, decreased with increased temperature, and increased as the exhaust flow exceeded the supply flow rate. When the same model ERV was installed and operated in full-scale test house, the FTE was quite high: approximately 29%, with 92-100% of the formaldehyde transfer attributed to air leakage. Although the device has a rating of 10% air leakage, the air leakage through the device when installed in a home can be significantly higher (27-28%).

The FTE of about 29% found in the field experiments was somewhat higher than the value of 18.9% found in chamber experiments that had similarly imbalance between supply and exhaust flows. The discrepancy between field and chamber experiments may have been caused by how the device was installed or by variation between different units of the same model device. In particular, if ducting is not well sealed to the ERV unit, additional air leakage between streams can occur. There may also be some variation in construction between individual ERV units. It is not expected that all models of ERVs would have the same performance as this ERV. However, the formaldehyde transfer efficacy in this unit is sufficiently high to raise concerns. If the installation process can lead to significant leakage, then air transfer of formaldehyde is likely to be an issue in other ERV models as well.

ERVs are used to provide ventilation in an energy efficient manner. One important purpose of ventilation is to dilute indoor air contaminants such as formaldehyde that is commonly emitted by building materials, furnishings, and other products found in homes. However, our results show that the supply air provided by one common ERV model contained significant levels of formaldehyde. Thus, ERVs may be significantly less effective at removing formaldehyde than other modes of ventilation. As a result, the ventilation benefit provided by the ERV at a given flow rate may not be realized, and higher ventilation rates are necessary to adequately dilute indoor contaminant concentrations. If the ventilation rate is increased to dilute indoor contaminants, the energy required to condition the ventilation air will also increase, proportionally.

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