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Research Article

Contaminant Crossover in Residential Energy Recovery Ventilators: Mass Spectrometric Analysis and Introducing Remediation Measures

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Abstract

Background and Objective: Energy Recovery Ventilators (ERV) are increasingly present in residential environments to enable the energy-efficient provision of controlled outdoor air ventilation. In this work, we investigated pollutant transport through a typical residential ERV as a potential pathway for re-entrainment of indoor air pollutants into the outdoor ventilation air supplied to an indoor space. Specifically, we investigated the transfer of Volatile Organic Compounds (VOCs) through the sandwiched membrane matrix of the ERV core, between two adjacent air streams. **Materials and Methods:** Pollutant transfer efficiency is calculated for experiments intentionally injecting two common indoor VOCs (acetone, Isopropanol (IPA)) and the behaviour of transfer is studied for different ERV exhaust and supply flowrates (supply, exhaust, balanced scenarios). **Results:** Maximum pollutant transfer efficiency of 17% is recorded for isopropanol at balanced (equal supply and exhaust airflow rates) conditions at intake and exhaust airlines. Maximum pollutant transfer efficiency of 26% and a minimum of 5.3% for unbalanced CFM settings are obtained. For VOCs studies, we observed short response times of <10s from starting injection of VOCs into the indoor exhaust air stream until the concentration at the indoor supply air stream reaches to steady state. **Conclusion:** The airflow rates of intake and exhaust streams of a typical membrane ERV can tremendously impact the contaminant crossover back to the residential space. Also, a membrane ERV can demonstrate a fast response to contaminant crossover.

Key words: Mass transfer, volatile organic compounds, Proton Transfer Reaction Mass Spectrometry (PTR-TOF), Indoor Air Quality (IAQ), transfer efficiency, response time analysis, pollutant dynamics

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Indoor Air Quality (IAQ) is an important aspect for maintaining healthy lifestyles and reducing illnesses that are mainly related to the respiratory system^{1,2}. Previous studies reported that even at low levels of concentrations of pollutants, such as VOCs, particulate matter (PM) and Carbon Dioxide (CO₂) in indoor space is associated with respiratory and other adverse health outcomes in occupants². The best method to achieve a good IAQ is providing sufficient ventilation for the building space so far³.

Among the multiple methods available to produce mechanical ventilation, energy recovery ventilators (ERVs) become a necessary device. The ERVs help to extract heat and moisture from exhaust stale air streams and transfer them to supply fresh air streams by saving energy that is required for direct heating and humidification. Yang *et al.*⁴ concluded that ERVs not only improves the IAQ but also reduce the building energy consumption by recording 34.56% efficiency, in a set of experiments they performed based on ERV in an indoor stadium. Among the few types of ERVs available for applications, membrane type ERVs are widely used due to their simplicity and versatility in operation⁴.

While ERVs offer the opportunity for energy-efficient ventilation, prior studies indicate that mass transport of contaminants from the exhaust to supply airflow of ERVs are possible for an indoor burst of pollutants due to everyday operations⁵⁻⁸. The mass transport in ERVs is mainly assessed by the factor referred to as exhaust air transfer efficiency (EATR)⁵. Hult *et al.*⁵ performed experiments on rotary enthalpy ERV based on formaldehyde crossover to evaluate EATR value. The EATR calculation process introduced by studies⁵⁻⁷ is related to the definition by ASHRAE. Hult *et al.*⁵ found that the EATR values range from 10-29% for a rotary enthalpy wheel, concluding that the bulk of the transfer is due to the air leakage from the wheel and 30% of the transfer process due to absorption and desorption. Patel *et al.*⁶ performed studies in contaminant cross over in run-around membrane energy exchangers (RAMEE) using the same EATR parameter concept. They used toluene (C₇H₈) and Formaldehyde (HCHO) as trace VOCs to test the re-entrainment. They have reported that EATR for toluene falls 2.3-3.4±3.5% and 4.5-6.4±3.6% for formaldehyde. Importantly, they have stated that there is a negligible transfer of low water-soluble VOCs (toluene), however, a detectable transfer from high water-soluble VOCs (formaldehyde) in RAMEE type ERV. Furthermore, for RAMEE's they found that EATR values are insensitive to changes in airflow rates, liquid desiccant flow rates, latent effectiveness and environmental conditions. Huizing *et al.*⁷ reported EATR

values observed by previous researchers in their paper. They used CONTAM software to model pollutant transfer rates under different permeabilities of the membrane material. In addition, Huizing *et al.*⁷ performed experiments considering a single membrane by an experimental test rig fabricated to ASTM F-739 standard and their EATR values ranged from 0-50%. Weerasekera and Laguerre⁹ introduced a coupled continuum scale transport model for contaminant crossover in ERVs. Their simulations were based on microscopic aspects of contaminant transfer between a single membrane of an ERV. They used PTR-TOF MS data to validate their simulation results⁹. Further studies have been performed by Weerasekera and Cao¹⁰ on contaminant diffusion in polymeric membranes which are widely utilized as a material for membrane cores in ERVs. They have proved the contaminant crossover behaviour by applying multiple modelling approaches (Fick's diffusion, Darcy pore flow model, computational fluid dynamics) and arrived at convergence with all models which were used in study¹⁰.

In this work, we expand on the above prior studies investigating VOC crossover in fixed membrane core ERVs adding another two important VOCs: Acetone and isopropyl alcohol. These compounds are selected since they are ubiquitous and present at high variable concentrations in an indoor environment and not previously studied in literature¹¹. Through this study, we have evaluated the EATR values for fixed membrane ERVs also studied the response behaviour of membrane ERV to pollutant crossover to close this research gap.

MATERIALS AND METHODS

Experimental apparatus: We built an experimental setup using a residential-scale commercial ERV (Panasonic Intelli-Balance-100). The study was performed at the Department of Biochemistry and Molecular Biology of Oregon State University, Corvallis OR, USA from August 2019 to May 2021 using Proton Transfer Reaction Time of Flight mass spectrometry (PTR-TOF) as the main concentration measurement instrument. The ERV has a maximum airflow rate of 100 ft³/min and a minimum of 50 ft³/min for both intake and exhaust airlines with a possibility of 10 ft³/min increments for both directions. The schematic of the experimental setup based on the ERV is shown in Fig. 1. Figure 2a represents the real-time nomenclature of ERVs ports and airflow rates and Fig. 2b shows the mass spectrometer (PTR-TOF-1000) that has been used for measurements, PTR-TOF. The ERV ports are named based on the flow at each port, e.g., the indoor exhaust air duct, where the air is taken

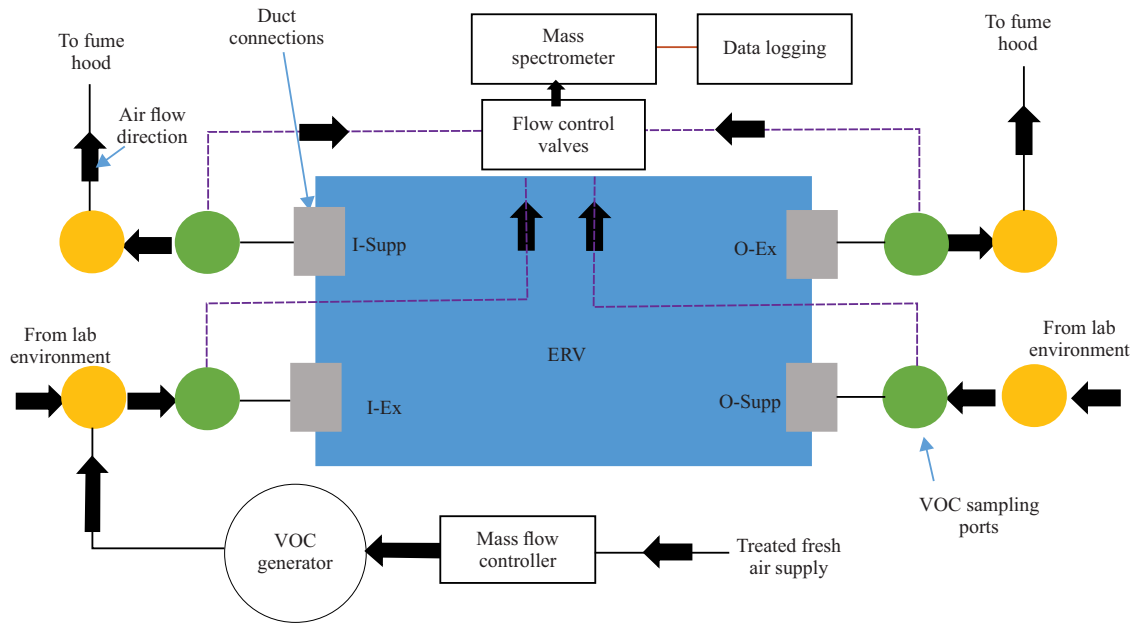


Fig. 1: Schematic of the experimental setup and port nomenclature

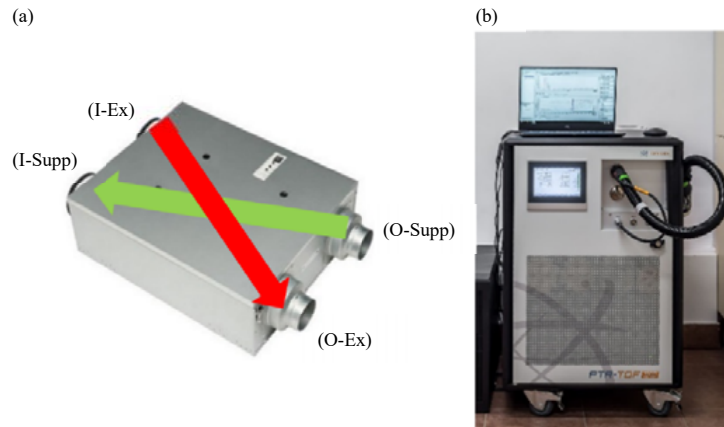


Fig. 2: Real-time ERV port nomenclature and mass spectrometer, (a) Panasonic Intelli-Balance 100 ERV and identification of airflow ports and airflow directions and (b) Ionicon analytik PTR-TOF-1000 MS

from the indoor space, is named as I-Ex port. The port which is exhausting indoor air to the outdoor environment is named as O-Ex. The port which brings fresh air from outdoors is named as O-Supp. And finally, the port that supplies “fresh” air to the indoors is named I-Supp. Figure 1 represents this naming convention, which will be used in subsequent presentations and discussions of experimental results. The pollutant was injected into the I-Ex port of the ERV using the VOC generating set up as shown in Fig. 3.

Transfer efficiency: Mass of the pollutant transported through each port of the ERV is based on calculating mass flux to the mass flow rate of the compound. By knowing the volumetric flow rate and concentrations at each port, mass flow rate M_x can be calculated as⁸:

$$M_x = C_x \times VFR_x \quad (1)$$

where, C_x is the concentration measured at the x^{th} port of the ERV and VFR_x is the volumetric flow rate measured at the

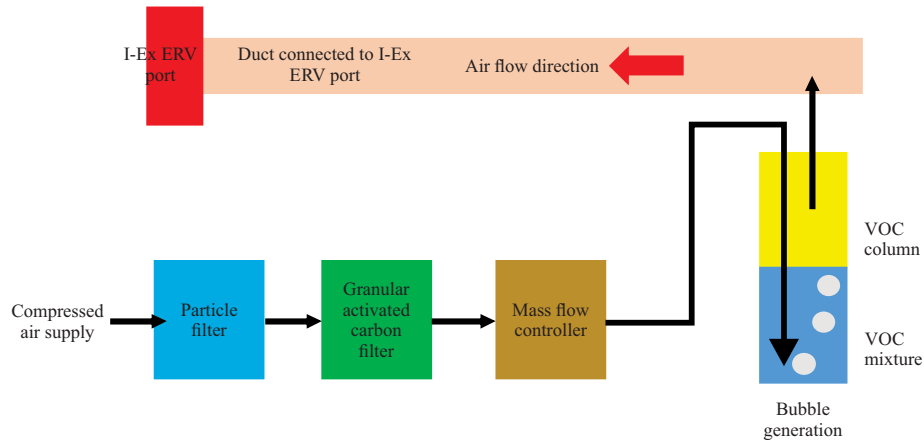


Fig. 3: Schematic of the VOC generating setup and connection to I-Ex ERV port

Table 1: Significance of balance and unbalanced CFM settings

CFM setting (exhaust line/supply line)	Significance of the CFM setting
50/50	Equal CFM settings in both exhaust and supply streams from ascending order
70/70	
100/100	
50/100	High CFM difference in two streams
100/50	
60/90	Medium CFM difference
90/60	
70/80	Low CFM difference
80/70	

same port. By taking the concentration measurements from each ERV port, pollutant transfer efficiency can be calculated as:

$$EATR = \frac{M_{I-Supp} - M_{O-Supp}}{M_{I-Ex} - M_{O-Supp}} \quad (2)$$

In the above equation, both mass flow rates are normalized by an outdoor mass flow rate of the compound (M_{O-Supp}) to avoid the inconsistency due to the variation of outdoor compound concentration. Where subscript x is replaced by the port nomenclature as in Fig. 1. For unbalanced CFM conditions, equation 2, can be simply multiplied with the factor, Supply CFM/Exhaust CFM for convenience. This description can be represented mathematically as:

$$EATR = \frac{C_{I-Supp} - C_{O-Supp}}{C_{I-Ex} - C_{O-Supp}} \times \frac{VFR_{intake}}{VFR_{exhaust}} \quad (3)$$

where, VFR_{intake} is the intake line CFM value which is equal to VFR_{I-Supp} and VFR_{O-Supp} and $VFR_{exhaust}$ is the CFM of the

exhaust line and it is equal to VFR_{I-Ex} and VFR_{O-Ex} . For a balanced CFM arrangement and $\frac{VFR_{intake}}{VFR_{exhaust}} = 1$ and for an unbalanced CFM arrangement $\frac{VFR_{intake}}{VFR_{exhaust}}$ takes a positive value.

Experimental protocol: From the various CFM settings possible for intake and exhaust air streams, we extracted the most significant CFM arrangements that can mainly be considered. Concentration measurements at each port are established according to these CFM settings. As a preliminary approach, to observe the pattern of VOC transfer efficiency, we performed our experimental matrix with equal, low difference and high difference CFM arrangements of exhaust and intake air streams. This matrix is shown in Table 1.

Maintaining mass balance closure: The measurements that are taken can be validated by analyzing the general mass balance of the compound for each CFM setting. Respectively, general mass balance can be performed as a derivative of equations 2 and 3 as follows:

$$M_{sunked} = M_{I-Ex} - M_{O-Ex} \quad (4)$$

$$M_{sourced} = M_{I-Supp} - M_{O-Supp} \quad (5)$$

RESULTS AND DISCUSSION

Transfer efficiencies: The transfer efficiency for each and individual CFM setting is calculated and compared by the concentration data which is obtained. Considering compound concentration, which is recorded as ppb from mass spectrometer software, is converted to based on the molecular weights of acetone (59 g mol^{-1}) and IPA

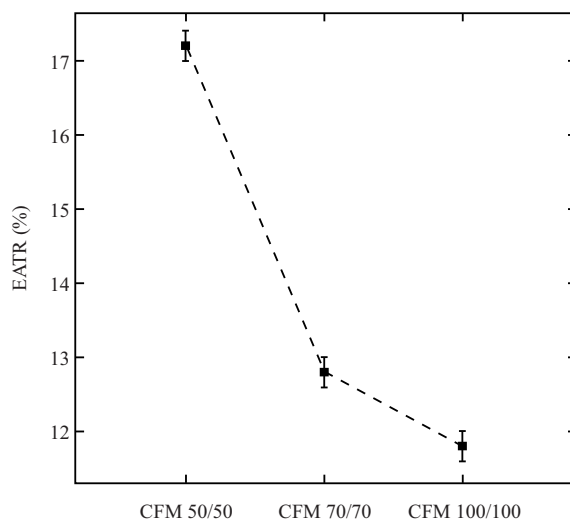


Fig. 4: EATR values for balanced CFM settings for Isopropyl alcohol (C_3H_8O)

Table 2: Generalized EATR values recorded in the literature

Publication	EATR value	Type of device
Hult <i>et al.</i> ⁵	10-29%	Rotary enthalpy wheel
Patel <i>et al.</i> ⁶	0-6.4%	Run-around membrane type
Huizing <i>et al.</i> ⁷	0-50%	Membrane based ERV

(60.1 g mol^{-1}) and CFM values are converted to while applying to equation 1 for equal CFM conditions. The following efficiencies are computed by taking the average value of the fluctuating concentration for the sampling period and these average values are listed in the appendix. The error bars are developed under the methodology of the common error propagation method starting from the standard deviation of an individual measurement following the laws of arithmetic. Table 2 represents generalized EATR values obtained by previous researchers to provide context for the range of EATR values we report.

Figure 4-6 represents the transfer efficiency (EATR) values for isopropyl alcohol through the ERV core. Also, when increasing the CFM conditions, the transfer efficiency of the compound is decreasing. One possible explanation for this occurrence is, flow velocities inside core channels are higher with higher CFM values, thus, the pollutant has less contact time with the membrane-air interfaces. Therefore, the pollutant is carried away from the flow to the exhaust port, reducing mass transfer across the membranes.

Unbalanced CFM condition-1 as introduced in Fig. 5, is based on setting low CFM values in the exhaust line and high CFM values in the indoor supply line. The above plot is obtained for balanced and unbalanced CFM values for isopropyl alcohol satisfying the overall deviation of

compound mass balance $<5\%$. As the unbalanced settings approach balanced conditions, the EATR (compound transfer efficiency) values calculated approach to respective balanced conditions. For example, in setting 70/80, an EATR of 10.1% is measured, which is near to the EATR of the balanced CFM setting (70/70) of 12.8%. Under conditions with greater exhaust/inlet imbalance, higher compound transfer efficiency for IPA is recorded, with 26.2% of EATR at 50/100 CFM setting.

When high CFM values are set for the exhaust line and low CFM values for the supply line, as in Fig. 6, shows lower transfer efficiencies. The lowest EATR was recorded at 100/50 exhaust/supply airflow, at 5.35%. Again, as the imbalance between exhaust and supply is reduced, we observe an EATR that approaches respective imbalanced conditions (e.g., 80/70 results in an EATR of 9.2% vs 70/70 resulting in EATR of 12.8% (Fig. 5).

The behaviour of the transfer efficiencies for unbalanced conditions can be successfully explained through species advection and diffusion theory, according to Weerasekera *et al.*⁹, as they already introduced explanations related to membrane type ERVs based on this theory. For unbalanced CFM condition-1, relatively low CFM values increase the interface contact time of the compound with the membrane-air interface providing more opportunity for interface mass transfer at the exhaust side. Relatively high CFM values at the supply side have high advective currents and low static pressures compared to the exhaust side, providing positive pressure induced diffusion of the compound from the exhaust side to the supply side. It is entirely clear that the

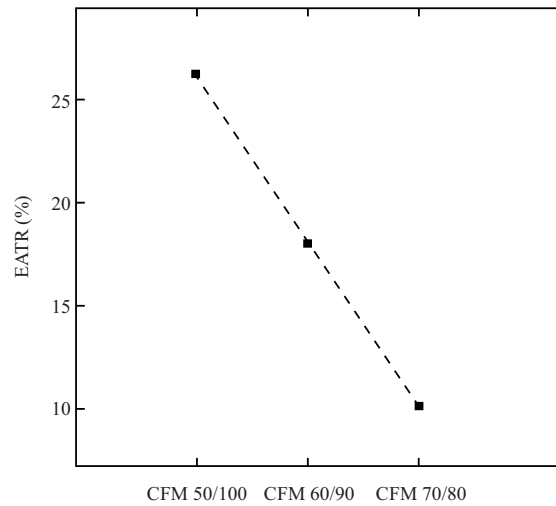


Fig. 5: EATR values for unbalanced CFM settings as in condition 1 for Isopropyl alcohol (C_3H_8O)

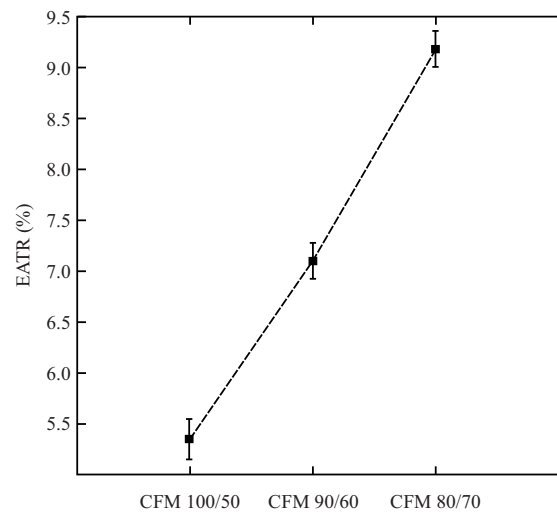


Fig. 6: EATR values for unbalanced CFM settings as in condition 2 for Isopropyl alcohol (C_3H_8O)

opposite phenomenon occurs at unbalanced CFM condition-2 creating negative pressure induced diffusion from the exhaust to supply sides simultaneously creating lower transfer efficiencies.

A more detailed explanation of the behaviour of the transfer process can be presented in Fig. 7. Where, from the microscopic point of view, the development of the ERV membrane core can be simplified to a system containing two channels separated by a porous membrane. Under ideal balanced CFM conditions, static pressures at either side of the membrane can be approximated as equal based on equal airflow velocities at either side of the channel core

channels. Therefore, the static pressure gradient across the membrane ($P = P_1 - P_2 / L$) can be approximated to zero. In this type of setting, apart from the air leakage, the only pollutant transfer process is Fick's diffusion. For unbalanced CFM condition-1, the exhaust side has a higher static pressure and the supply side has a lower static pressure, therefore, $\Delta P > 0$ creates a pressure-induced diffusion process from the exhaust side to the supply side. On contrary, for unbalanced CFM condition 2, $\Delta P < 0$ is observable. Therefore, this negatively induced pressure gradient is reducing the diffusion process creating lower efficiencies of pollutant transfer.

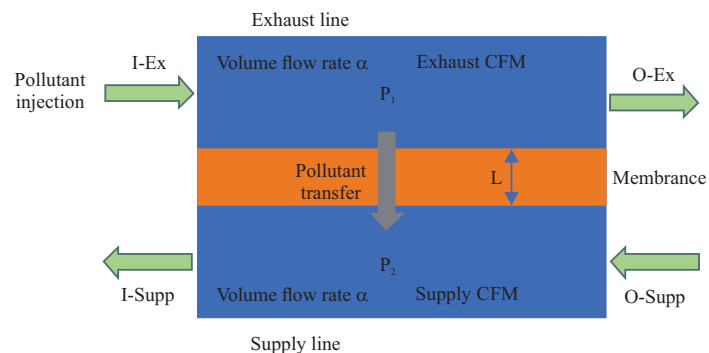


Fig. 7: Microscopic depiction of the pollutant transfer process

where, P_1 and P_2 are static pressures at the exhaust side and supply side and L is the membrane thickness

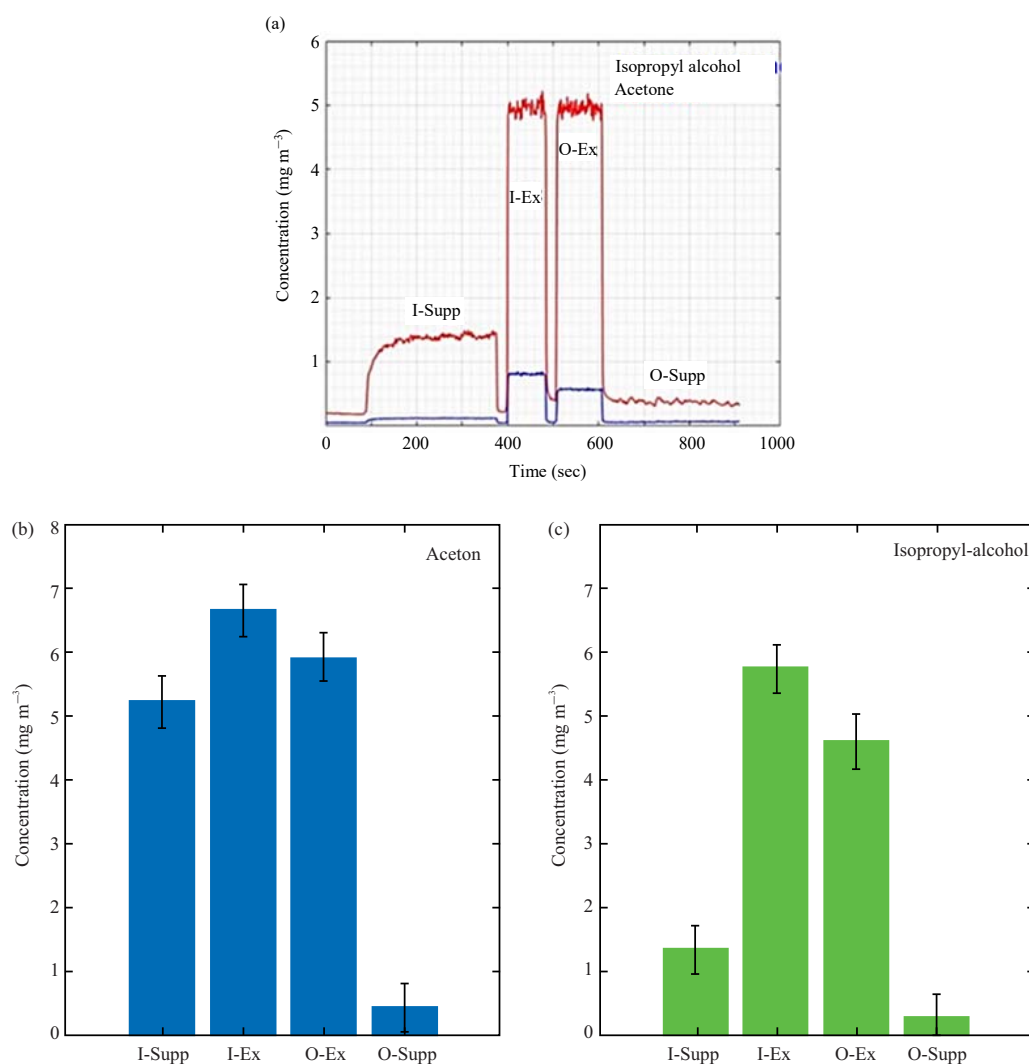


Fig. 8(a-c): Abnormality in the crossover of acetone as a contaminant at balanced CFM conditions, (a) Time series plot for the experiment that was performed for 50/50 equal CFM setting (Spike identification is same as in Fig. 4) and (b) Comparative bar graph for mean concentrations at each sampling port for same CFM setting
Note: Magnitude of concentration for each compound measured from the zero level for above bar graph

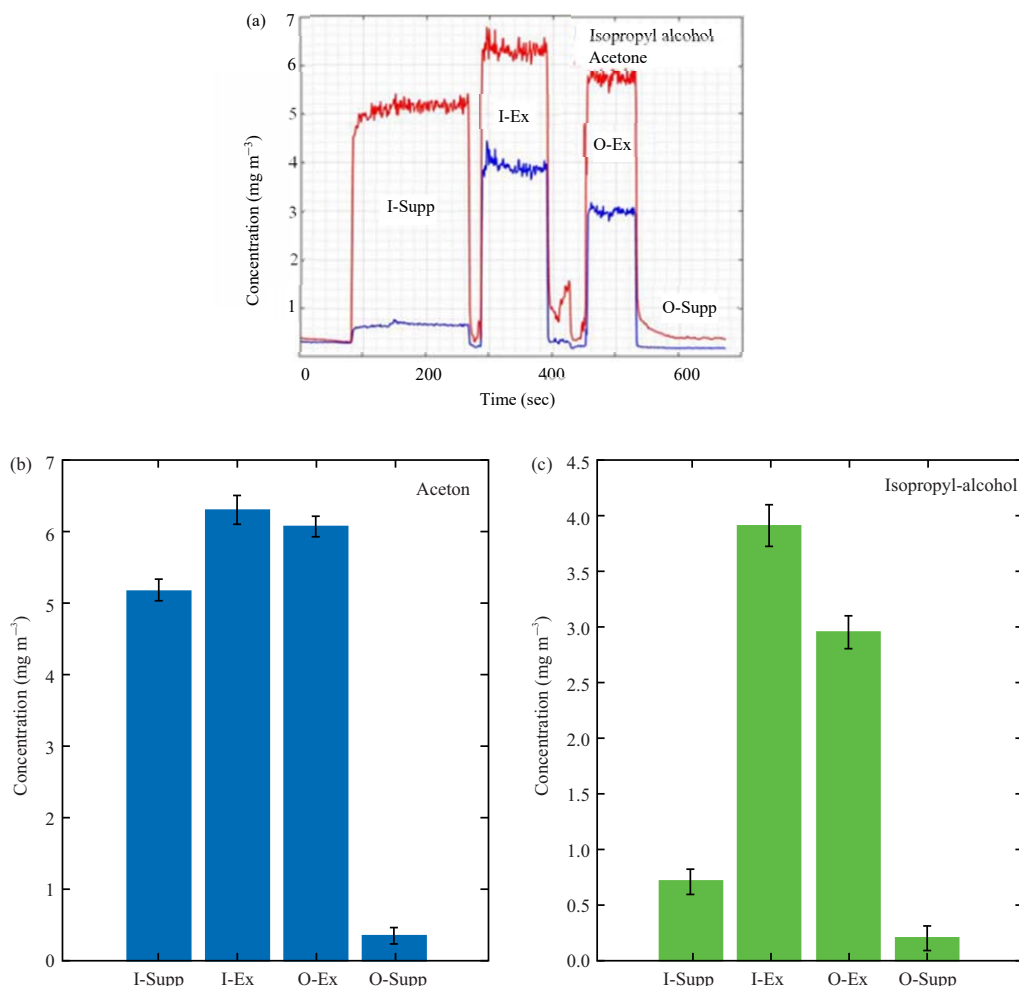


Fig. 9(a-c): Abnormality in the crossover of acetone as a contaminant at unbalanced CFM conditions, (a) Time series plot for the experiment that was performed for 50/100 CFM setting (Spike nomenclature is same as in Fig. 4), (b) Comparative bar graph for the concentrations at each sampling port for same CFM setting

Note: Magnitude of concentration for each compound measured from the zero level for above bar graph

Abnormality of entrainment of acetone: Transfer efficiencies in Fig. 6-8 are computed for isopropyl alcohol where satisfactory mass balance with a deviation range <5%. Fig. 8a-c and 9a-c represent one result of a typical experiment performed on acetone and isopropyl alcohol with balanced (50/50) and unbalanced (50/100) CFM conditions, respectively. Figure 8b-c and 9b-c compare the results between isopropyl alcohol and acetone. Here, acetone-isopropyl alcohol mixture is injected into the I-Ex port and entrainment characteristics are observed. It is visible from the time series plot, that, acetone concentration at the I-Supp port has an unacceptably high value compared to its value at the exhaust port (I-Ex, O-Ex) (Fig. 8b). However, isopropyl alcohol acts normally satisfying regular mass balance conditions. From this result, we hypothesize that there is a high absorption and emission

rate for acetone in the membrane core and there can be a possibility of accumulation of this compound in the core. Furthermore, preliminary background concentration tests performed for acetone before each experiment confirmed that there is no late emission of acetone from the ERV core. This result is a topic for further evaluation under different research.

Response from the ERV for pollutant transfer: It is of utmost importance to study the reaction time of the ERV to pollutant transport. Therefore, this study is performed in two aspects. In the first case, continuous measurements are taken at the I-Supp port conforming compound concentration at this port that is at the laboratory VOC concentration. The pollutant is supplied afterwards and supply start time vs concentration variation at the I-Supp port is examined. From the same way

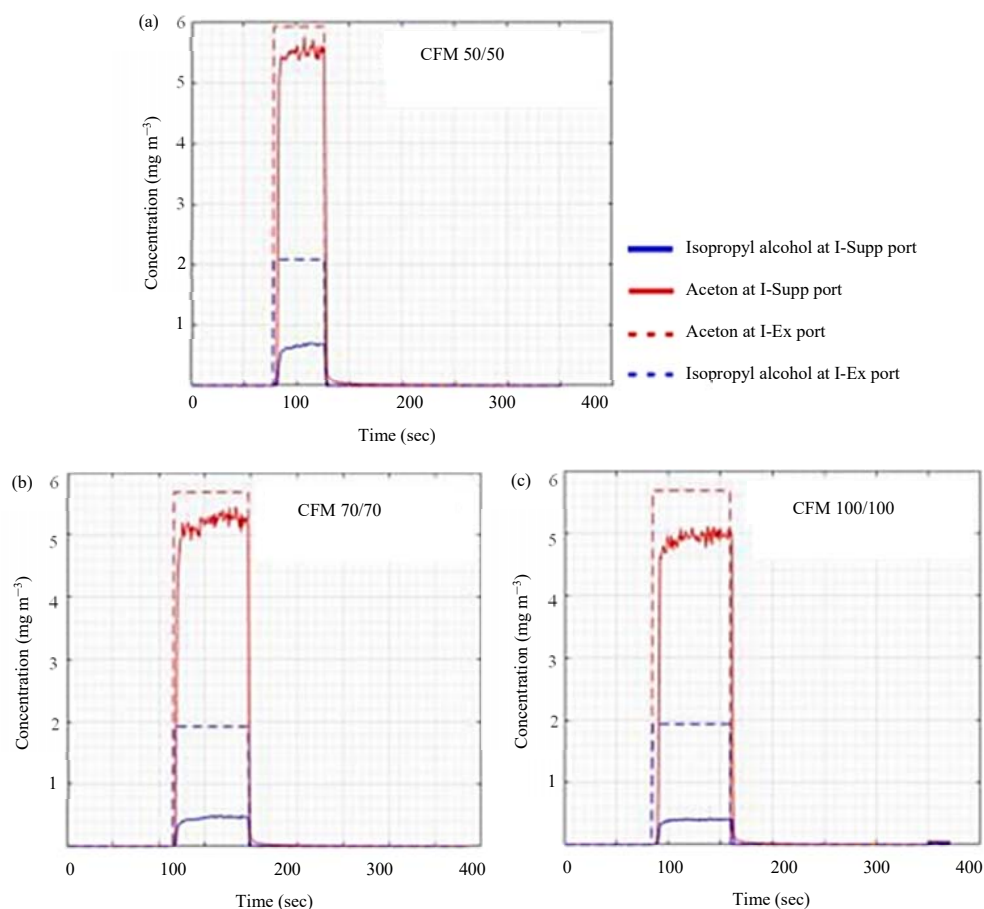


Fig. 10(a-c): ERV response time measurement process for trace compounds acetone and isopropyl alcohol, (a) Response analysis at 50/50 CFM setting, (b) Response analysis at 70/70 CFM setting and (c) Response analysis at 100/100 CFM setting

Table 3: Overview of the response time measured for equal CFM experiments extracted from time series plots considering both compounds

Time series plot	Injection start point	Injection stopping point	Response time to achieve first concentration spike at I-Supp port	Response time to achieve steady ambient concentration at I-Supp port
Figure 10a	79 sec	127 sec	7 sec	196 sec
Figure 10b	116 sec	197 sec	8 sec	226 sec
Figure 10c	85 sec	159 sec	10 sec	249 sec

concentration at the I-Supp port after stopping the VOC supply is also observed. Figure 10 presents the time series plots of raw measurements for three equal CFM settings (50/50, 70/70 and 100/100) in response time analysis and Table 3 represents the overview of the response time experiments performed using isopropyl alcohol as the trace compound.

From the above results, it is evident that the device has relatively fast response times when considering re-entrainment start time from the beginning of VOC supply to the I-Ex port. The response time to reach the steady-state concentration of the compound after the start of supply can be averaged to <10s. The response is not instantaneous after

cessation of injection and there exists a lag before a return to steady-state conditions with the I-Ex concentration post-emission event. We hypothesize that the driver for this occurrence is the re-emission of absorbed compounds into the membrane matrix. Note that all these experiments are performed after conforming the concentrations of each ERV port is equivalent to laboratory VOC concentrations. Therefore, effects from outside factors, apart from VOC supply to the I-Ex port are avoided.

When comparing EATR values for fixed membrane-based ERVs with rotary enthalpy wheels and run-around type ERVs, we can consider that fixed membrane-based ERVs are more vulnerable for pollutant re-entrainment based on the current

study as well as from previous studies⁵⁻⁷. The current study shows a maximum EATR value of 26.2% which falls between the predicted EATR range as presented by Huizing *et al.*⁷. By increasing the exhaust airflow rate compared to intake air flow rate, pollutant re-entrainment can be significantly reduced due to increased advection currents in the exhaust line also by reducing membrane-air interface diffusion⁹. As the main implication from the study, in a typical practical fixed membrane ERV application, we recommend operating an ERV in unbalanced conditions with high exhaust air flow rate and low intake air flow rate to reduce the impact from an indoor pollutant burst on occupants while still maintaining required fresh air supply rates.

CONCLUSION

Contaminant crossover through residential energy recovery ventilators is studied through this work using isopropyl alcohol and acetone as the trace compounds. We observed that the minimum transfer efficiency (5.35%) is observed when ERV is operated under unbalanced CFM conditions with higher exhaust line CFM value compared to input line CFM. The highest transfer efficiency (26.2%) is observed when exhaust line CFM is a low value. Compared to the transfer behaviour of isopropyl alcohol, acetone demonstrated an anomaly of transfer observing late emission from the ERV core resulted in increased crossover concentrations. We also conclude that membrane ERVs are highly vulnerable to contaminant crossover showing low response time to indoor related pollutant bursts.

SIGNIFICANCE STATEMENT

This study discovers the potential of contaminant crossover in membrane ERVs that can be beneficial for understanding the vulnerability of different membrane-type ERV designs and membrane materials for contaminant crossover. The current study also contributes to implementing remediation measures to reduce such contaminant crossover by efficient settings of intake and exhaust airflow rates of a typical membrane ERV. This study will help the researcher to uncover the critical areas of achieving better IAQ levels that can tremendously improve the occupant performance and health risks where critical research is necessary.

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REFERENCES

1. Cincinelli, A. and T. Martellini, 2017. Indoor air quality and health. *Int. J. Environ. Res. Public Health*, Vol. 14. 10.3390/ijerph14111286.
2. Zhong, L., F.C. Su and S. Batterman, 2017. Volatile organic compounds (VOCs) in conventional and high performance school buildings in the U.S. *Int. J. Environ. Res. Public Health*, Vol. 14. 10.3390/ijerph14010100.
3. Rosbach, J.T.M., M. Vonk, F. Duijm, J.T. van Ginkel, U. Gehring and B. Brunekreef, 2013. A ventilation intervention study in classrooms to improve indoor air quality: The FRESH study. *Environ. Health*, Vol. 12. 10.1186/1476-069X-12-110.
4. Yang, P., L. Li, J. Wang, G. Huang and J. Peng, 2015. Testing for energy recovery ventilators and energy saving analysis with air-conditioning systems. *Procedia Eng.*, 121: 438-445.
5. Hult, E.L., H. Willem and M.H. Sherman, 2014. Formaldehyde transfer in residential energy recovery ventilators. *Build. Environ.*, 75: 92-97.
6. Patel, H., G. Ge, M.R.H. Abdel-Salam, A.H. Abdel-Salam, R.W. Besant and C.J. Simonson, 2014. Contaminant transfer in run-around membrane energy exchangers. *Energy Build.*, 70: 94-105.
7. Huizing, R., H. Chen and F. Wong, 2015. Contaminant transport in membrane based energy recovery ventilators. *Sci. Technol. Built Environ.*, 21: 54-66.
8. Boardman, C.R. and S.V. Glass, 2015. Moisture transfer through the membrane of a cross-flow energy recovery ventilator: Measurement and simple data-driven modeling. *J. Build. Phys.*, 38: 389-418.
9. Weerasekera, N.D. and A. Laguerre, 2019. Coupled continuum advection-diffusion model for simulating parallel flow induced mass transport in porous membranes. *Int. J. Sci. Res.*, 8: 694-700.
10. Weerasekera, N.D. and S. Cao, 2019. Multifaceted convergence study for evaluating gas diffusion parameters of polymeric membranes. *J. Eng. Appl. Sci.*, 6: 57-63.
11. Tang, K.K.W. and M.R. Mahmud, 2021. The accuracy of satellite derived bathymetry in coastal and shallow water zone. *Int. J. Built Environ. Sustainability*, 8: 1-8.