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Determination of personal exposure to volatile organic compounds and their health risks after the use of mosquito repellents in residential environments using passive sampling

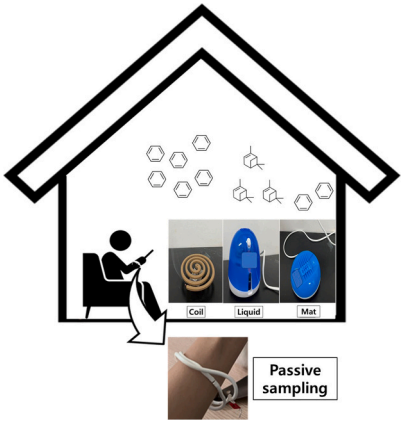
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HIGHLIGHTS

- The emission characteristics of coil-, mat-, and liquid-type mosquito repellents were observed.
- ePTFE passive sampler was used to quantify personal exposure to indoor VOCs.
- Notable increase of indoor benzene was observed for coil- and mat-type mosquito repellents.
- α-Pinene concentration increased significantly following the use of liquid-type mosquito repellent.
- Low plausible hazard for adults following the use of coil- and mat-type mosquito repellents

GRAPHICAL ABSTRACT



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ABSTRACT

The ubiquitous use of mosquito repellents in homes across Asia, Africa, and South America is related with human exposure to indoor volatile organic compounds (VOCs). There are three primary types of mosquito repellents: those in the form of coils, mats, and liquids. The repellent mechanisms of these products are distinct, resulting in the generation of varying types of VOCs during the repellent process. In this study, the emission characteristics of commercial coil-, mat-, and liquid-type mosquito repellents were observed in a laboratory chamber using real-time measurement. A previously developed personal passive sampler, ePTFE PS, was used to quantify personal exposure to indoor VOCs while 86 volunteers habitually used those three representative types for 3 h in

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their residence. Notable increase of indoor benzene was observed for coil- and mat-type mosquito repellents, while α-pinene concentration increased significantly following the use of liquid-type mosquito repellent. The average incremental cancer risks for benzene were 10^{-6} to 10^{-4} for adults following the use of coil- and mat-type mosquito repellents. The average non-cancer risks for all chemicals were <1 after the use of three types of mosquito repellents. Considering the potential human health risks associated with byproducts (e.g., particulate matter or carbon monoxide from incomplete combustion) emitted after mosquito coil use, further research on this topic is warranted.

1. Introduction

Consumer products commonly used in residential environments such as scented candles, air fresheners, and essential oil diffusers, emit volatile organic compounds (VOCs) indoors (Nematollahi et al., 2019; Steinemann, 2015; Steinemann, 2019a; Steinemann, 2019b). Among these products, various types of mosquito repellents, which are ubiquitously used to repel mosquitoes in homes in Asia, Africa, and South America (Dubey et al., 2014; Islam et al., 2017), act as a source of indoor VOCs. For example, Zhu et al. (2018) showed that concentration of emitted benzene in a 0.35 m^3 test chamber by using coil- and liquid-type mosquito repellents was 40.7 ppb and 58.6 ppb, respectively (Zhu et al., 2018). The average concentrations of total VOCs emitted in a 56 m^3 test chamber by using the coil-, electric liquid- and electric mat-type mosquito repellents were 7.76 ± 4.72, 3.12 ± 0.87 and 1.19 ± 0.06 mg m^{-3}, respectively (Lu et al., 2020). The monitored average concentrations of benzene inside a 60 m^3 test chamber by using the coil-, electric liquid- and electric mat-type mosquito repellents were 4.0 ± 0.5, 1.0 ± 0.4, and 2.0 ± 0.2 μg m^{-3}, respectively (Wang et al., 2018). Benzene, one of the main VOCs emitted using mosquito repellents, is already well known for its carcinogenic potency (Gong et al., 2017; Wickliffe et al., 2020) through epidemiological studies showing that benzene causes acute myeloid leukemia. In addition, the International Agency for Research on Cancers concluded an association of multiple myeloma, non-Hodgkin's lymphoma, acute lymphocytic leukemia, and chronic lymphocytic leukemia with benzene exposure (American Cancer Society, 2016). Appropriate precautions, such as implementation of appropriate follow-up preventive measures based on benzene exposure assessment, can prevent its exposure in residential environment.

Previous studies assessed human health risk based on the emission characteristics of mosquito repellents observed in a test chamber (Lu et al., 2020; Wang et al., 2018; Zhu et al., 2018). However, the personal exposure to VOCs in the residential environment could be different from the estimate, as the habit of using consumer products and the effect of personal behavior was neglected. Sorption or deposition to indoor surfaces may also dramatically reduce the estimated exposure concentration from emission rate (Park et al., 2022). Various factors can cause indoor VOC concentrations to fluctuate. As a competent method to detect indoor VOCs, passive sampling can be used to evaluate the time-weighted average exposure considering these limits (Choi et al., 2023; Guo et al., 2004; Kim et al., 2023, 2024; McAlary et al., 2015; Park et al., 2022; Weisel et al., 2008; Zhou et al., 2011). Active sampling is also generally used to monitor short-term exposure to VOCs because it is a straightforward method (Amaral et al., 2010; Gallego et al., 2017; Horii et al., 2017). However, it may not be suitable for long-term monitoring or when the use of an air pump is limited (Li et al., 2020; Seethapathy et al., 2008; Vallecillos et al., 2020; Vallecillos et al., 2021; Vallecillos et al., 2019). Alternatively, passive sampling, which is convenient, easy to use, and inexpensive can circumvent problems of active sampling (Bohlin et al., 2007).

In our previous study, a passive sampler was developed to detect indoor VOCs (Kim et al., 2021). The sampler uses an expanded polytetrafluoroethylene (ePTFE) membrane with an adsorbent. The developed sampler has high accuracy and is rarely affected by air turbulence, as confirmed by comparison with real-time monitoring using a proton-transfer-reaction mass spectrometer. The developed sampler, ePTFE PS, was improved to increase its sampling rates and made it wearable for measuring personal exposure (Kim et al., 2023). The ePTFE PS exhibited high accuracy and was successfully used to monitor monoterpenes and volatile aromatic hydrocarbons in living environments (Kim et al., 2024). The tubes and adsorbents used in the ePTFE PS were relatively inexpensive, making it a cost-effective option.

In this study, the ePTFE PS was used to evaluate the personal exposure to volatile aromatic hydrocarbons and monoterpenes using the coil-, electric liquid-, and electric mat-type mosquito repellents, which are frequently used in South Korea. Emission characteristics of commercial products were observed in a benchtop 125 L acrylic chamber by real-time measurement using a proton transfer reaction time-of-flight mass spectrometer (PTR-TOF-MS). To assess personal exposure to VOCs in the residence, 86 volunteers who have used mosquito repellents were recruited, and their exposure levels were measured using ePTFE PS during their habitual use of mosquito repellents for 3 h. Finally, the health risks of VOCs from using different types of mosquito repellents were evaluated, based on the participants' personal exposure levels of VOCs measured by the ePTFE PS.

2. Materials and methods

2.1. Chemicals and instruments

The target volatile organic compounds (VOCs), including benzene, toluene, ethylbenzene, *m*,*p*-xylenes, *o*-xylene, styrene, limonene, and α-pinene were purchased from Sigma-Aldrich (Milwaukee, WI, USA), along with internal standards (toluene d_8 and chlorobenzene d_5). A solvent extraction method using dichloromethane (DCM) (Sigma-Aldrich) spiked with internal standards was employed to extract the VOCs from the adsorbent. The Agilent 6890A gas chromatograph and Agilent 5973N mass selective detector equipped with an Agilent DB-5 column (30 m × 0.25 mm × 0.25 μm) were used for gas chromatography–mass spectrometry (GC–MS) analysis. The injection volume was 2 μL and the split ratio was 5:1. Helium was used as the carrier gas at a constant flow rate of 1.0 mL min^{-1}. The oven temperature followed a specific protocol: it was initially set to 40 °C for 2 min, then increased at a rate of 10 °C min^{-1} until reaching 100 °C, and finally further increased at the same rate to reach 270 °C.

2.2. ePTFE PS

The passive sampler consisted of 500 mm ePTFE tubes (ID 2 mm; OD 4 mm, Huizhou Besteflon Industries Co. Ltd., Guangdong, Sijiaolou Industrial Zone) and 0.9 g of Optipore-L493 (Sigma Aldrich) adsorbent with a high sorption capacity for VOCs (Bonifacio et al., 2017). The tubes underwent Soxhlet extraction for 12 h using a mixture of 50 mL *n*-hexane and 50 mL acetone. The ePTFE PS was designed to be worn as a wristband (Fig. S1, Supplementary material). After the exposure period, the ePTFE PS was immersed in a 40-mL vial containing 10 mL of DCM and left for 1 day to extract VOCs. The concentration of VOCs in DCM was analyzed using GC–MS. Previous studies have shown that ePTFE PS has high accuracy compared to real-time analysis and active sampling techniques (Kim et al., 2021; Kim et al., 2023). Additionally, ePTFE PS has been validated for assessing the time-weighted exposure concentration of VOCs under real exposure conditions (Kim et al., 2024). The

time-weighted average concentrations of VOCs were calculated using the sampling rates and method detection limits (MDLs) from the previous study (Kim et al., 2024). To calculate the concentration of indoor VOCs (μg m^{-3}), the mass of VOCs extracted from the sampler (μg) was divided by the sampling volume (m^3). The sampling volume was determined by multiplying the VOC sampling rate by the sampling duration of 3 h. The mass of VOCs in the 20 blank ePTFE PS samples was taken into consideration. The extracted samples were calibrated using the internal standards toluene-d_8 and chlorobenzene-d_5.

2.3. Commercial products

Fig. 1 shows the results for three types of mosquito repellents: coil (a), electric liquid (b), and electric mat (c). The experimental conditions were set as follows: a gas flow rate of 2.00 cm^3 min^{-1}, an inlet temperature of 80.0 °C, an E/N ratio of 140 Td, and a pressure of 2.3 mbar in the drift tube. The *m/z* value of 79.054230 ($(C_6H_6)H^+$) was used to analyze benzene (Yuan et al., 2017). Three types of mosquito repellents were deployed in the 125 L acrylic chamber for 1 h each. However, due to clogging, the emission characteristics of the coil-type mosquito repellent could not be evaluated.

2.4. Panel study

Consumer panels of 28, 29, and 29 volunteers living in residential apartments, who have regularly used the coil-, electric liquid-, and electric mat-type mosquito repellents respectively, were recruited for the study. The volunteers were instructed to wear an ePTFE PS, as shown in Fig. S1, before using mosquito repellents for 3 h and while using the coil-, electric liquid-, and electric mat-type mosquito repellents for 3 h separately as they usually did. As shown in Table S1, volume of all apartments and ventilation status were surveyed. The panel study was conducted during August and September 2023. The indoor temperature of the residential apartment was assumed to be remained relatively stable at 23 °C at which the sampling rates of the ePTFE PS for VOCs were calibrated in the laboratory experiment. This temperature was selected because, in a previous study, it was found that the effect of temperature on passive sampling was not significant within a temperature variation of 10 °C (Kim et al., 2024). The study was approved by the Institutional Review Board of Korea University (approval number: KUIRB-2022-0264).

2.5. Health risk assessment

To minimize the uncertainty associated with using a single-point value for each parameter to estimate the risk for a population, we conducted a probabilistic health risk assessment by employing the Monte Carlo simulation technique (Thompson et al., 1992). After reviewing the toxicological information of the 8 VOCs detected in this study, we evaluated non-carcinogenic risks of 7 VOCs (e.g., benzene, toluene, ethylbenzene, *m,p*-xylene, *o*-xylene, styrene, and α-pinene), which had available toxicological information. Moreover, we evaluated carcinogenic risks of 2 VOCs (benzene and styrene), which were classified as 1A or 2A carcinogens by the International Agency for Research on Cancer (IARC) (IARC, 2019; Cheng et al., 2022). We considered inhalation as the major exposure routes for VOCs while using mosquito repellents in residential houses; therefore, we conducted an inhalation risk assessment. The inhalation non-carcinogenic and carcinogenic risk assessments were assessed using average daily dose (ADD) (Rostami et al., 2021). ADD was calculated as follow:

$$\mathrm{ADD}(\mu g/kg/day) = \frac{\mathrm{C}(\mu g/m^3) \times \mathrm{IR}\left(\frac{m^3}{day}\right) \times \mathrm{ET}(hour/day) \times \mathrm{EF}(day/year) \times \mathrm{ED}(year)}{\mathrm{AT}(year) \times 365(day/year) \times 24(hour/day) \times \mathrm{BW}(kg)} \quad (1)$$

where C (μg/m^3) represents the chemical concentrations sampled from ePTFE PS, ET (hour/day) represents the exposure time, EF (day/year) represents the exposure frequency, ED (year) represents the exposure duration, AT (year) represents the averaging time, IR (m^3/day) represents the inhalation rate, and BW (kg) represents the body weight. Detailed values and distributions of each parameter are presented in Table 1.

For the non-carcinogenic risk assessment, the hazard quotient (HQ) was used. The HQ value of >1 indicates a non-carcinogenic effect of concern (EPA, 1989).

$$\mathrm{HQ} = \frac{\mathrm{ADD}(\mu g/kg/day)}{\mathrm{RfD}(\mu g/kg/day)} \quad (2)$$

where the reference dose (RfD) (μg/kg/day) represents the acceptable level of exposure to VOCs. The RfD is calculated using the following equation:

$$\mathrm{RfD}(\mu g/kg/day) = \frac{\mathrm{RfC}(\mu g/m^3) \times \mathrm{IR}(m^3/day)}{\mathrm{BW}(kg)} \quad (3)$$

For the carcinogenic risk assessment, the lifetime cancer risk (LCR) was used. The LCR > 10^{-6} represents a carcinogenic effect of concern (EPA, 2018).

$$\mathrm{LCR} = \mathrm{ADD}(\mu g/kg/day) \times \mathrm{CSF}(\mu g/kg/day)^{-1} \quad (4)$$

where the cancer slope factor (CSF) (μg/kg/day)$^{-1}$ represents the inhalation cancer unit risk. For children, we multiplied age dependent adjustment factor 3 for 1 to 16 years to CSF (MOE, 2016).

3. Results and discussion

3.1. Emission characteristics of commercial products

Before conducting the panel study, we tested the emission characteristics of commercial mosquito repellents in a 125 L acrylic chamber using a PTR-TOF-MS with H_3O^+ as the selective reagent ion. Fig. 2 shows that the use of mat-type mosquito repellents resulted in an increase of benzene signals in arbitrary units, while the use of liquid-type mosquito repellents did not affect the signals. The average background signal of benzene in the chamber for 40 min was 8.4 arbitrary units. The average signals of emitted benzene in the chamber were 30 and 12 arbitrary units when using mat- and liquid-type mosquito repellents, respectively. When considering the background signals, the mat-type mosquito repellents emitted 5.3 times more benzene than the liquid-types on average over a period of 1 h. Although the coil-types emitted a significantly higher amount of benzene for a short period, the measurement was halted due to a clogged PTR-TOF-MS injector. This indicates that the emission of particulate matter from coil-type mosquito repellents is considerable, which is strongly correlated with an increased risk of cancer (Ciabattini et al., 2021).

For the calibration of PTR-TOF-MS for benzene, aliquots of a 5 % (v/v) benzene solution in ethanol were introduced to the bottom of the closed chamber and allowed to volatilize. After the solution volatilized

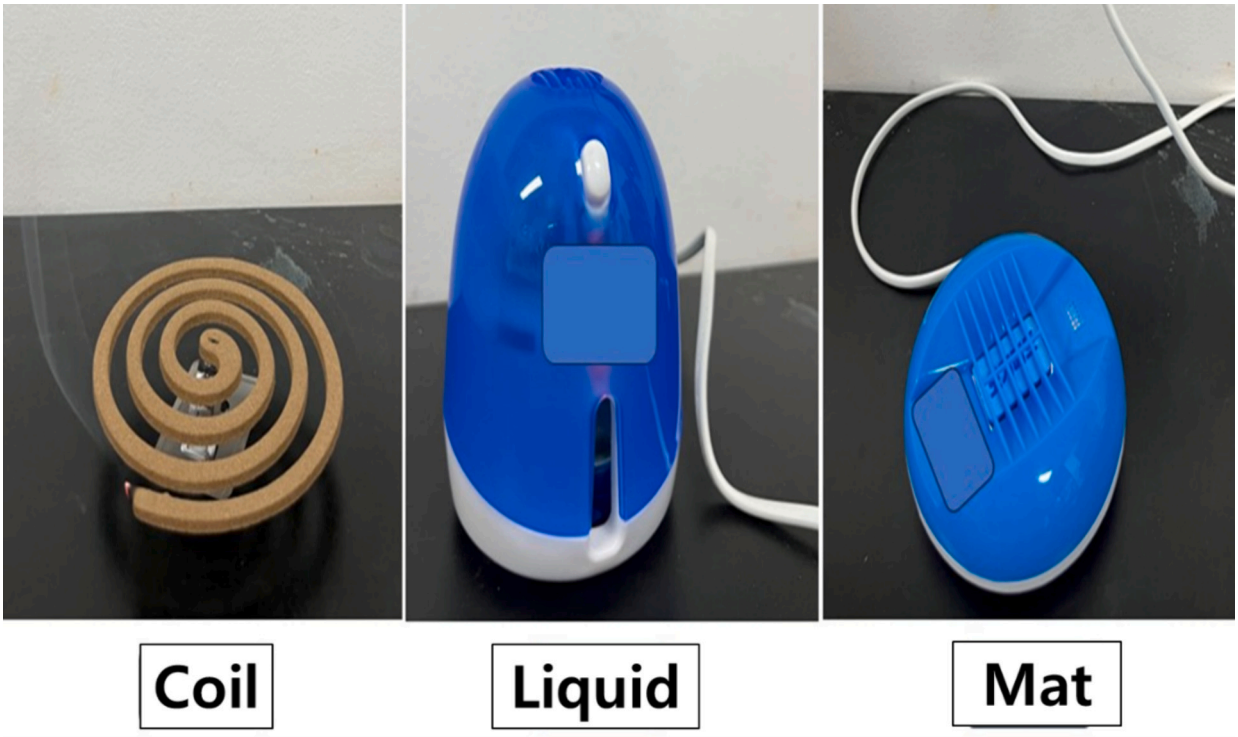


Fig. 1. Different types of mosquito repellents (a) coil, (b) liquid, (c) mat.

completely within 10 min, further aliquots of the solution were dropped to increase the gaseous benzene concentration in the test chamber. The PTR-TOF-MS signal for benzene was monitored by incremental addition to nominal concentrations of 0.15–22 μg L^{-1}. The signals in arbitrary units measured by PTR-TOF-MS and spiked concentration of benzene in the chamber demonstrated high linearity, with an R^2 value of 0.99, as shown in Fig. S2. As shown in Fig. S3, the measured emission rate of the mat-type mosquito repellent for benzene was 85 μg h^{-1}.

3.2. Panel study

Tables S1, S2, and S3 show the concentrations of VOCs in residential apartments before and after using coil-, electric mat-, and electric liquid-type mosquito repellents. The deployment of coil-type mosquito repellents significantly increased benzene concentrations in the residential apartments of 28 volunteers, as shown in Fig. 3(a). On average, benzene concentrations increased from 1.6 to 10.8 μg m^{-3} after deploying coil-

Table 1
Exposure parameters and values used in the probabilistic risk assessment.

Parameter	Definition (unit)	Value	Basis	Distribution type
C	Chemical concentration (μg/m^3)	Tables S2–S4	Sampling	Lognormal
IR	Inhalation rate (m^3/day)	19.92 for adult 15.12 for children	US EPA, 1997	Fixed value
ET	Exposure time (hour/day)	3.81 (±3.23) for coil-type 7.27 (±3.93) for mat-type 8.14 (±4.69) for liquid-type	MOE, 2021	Lognormal
EF	Exposure frequency (day/year)	92 (June-August-summer season)	Questionnaire	Fixed value
ED	Exposure duration (years)	70 for cancer risk (adult) 25 for non-cancer risk (adult) 5 for cancer/non-cancer risk (children)	MOE, 2016	Fixed value
AT	Averaging time (years)	70 for cancer risk 6.38 for non-cancer risk (adult) 1.26 for non-cancer risk (children)	MOE, 2016 (ED × EF)	Fixed value
BW	Body weight (kg)	68.65 (±12.88) for adult 24.86 (±11.74) for children	Questionnaire	Lognormal
RfC	Reference concentration (μg/m^3)	Benzene 30 Toluene 5000 Ethylbenzene 1000 *m,p*-Xylene 100 *o*-Xylene 100 Styrene 1000 α-pinene 4500	EPA IRIS	Fixed value
CSF	Inhalation cancer slope factor (μg/kg/day)$^{-1}$	Benzene 2.73E−05 Styrene 5.7E−07	RAIS CAL/EPA, OEHHA	Fixed value

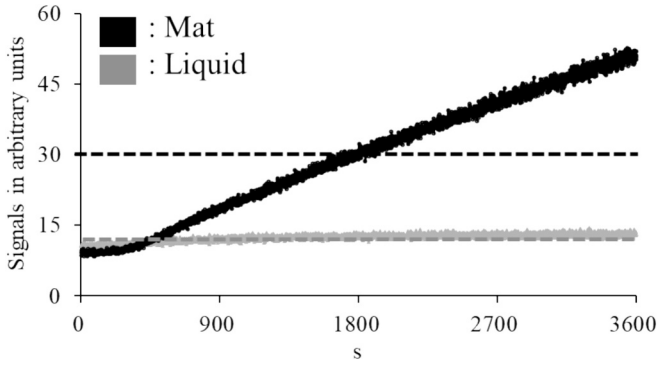


Fig. 2. Signals in arbitrary units of benzene measured by PTR-TOF-MS while using commercial mat (black) and liquid (gray) types of mosquito-repellents for 1 h in 125 L acrylic chamber, respectively. Line means real-time analysis and dotted line means time weighted average concentrations.

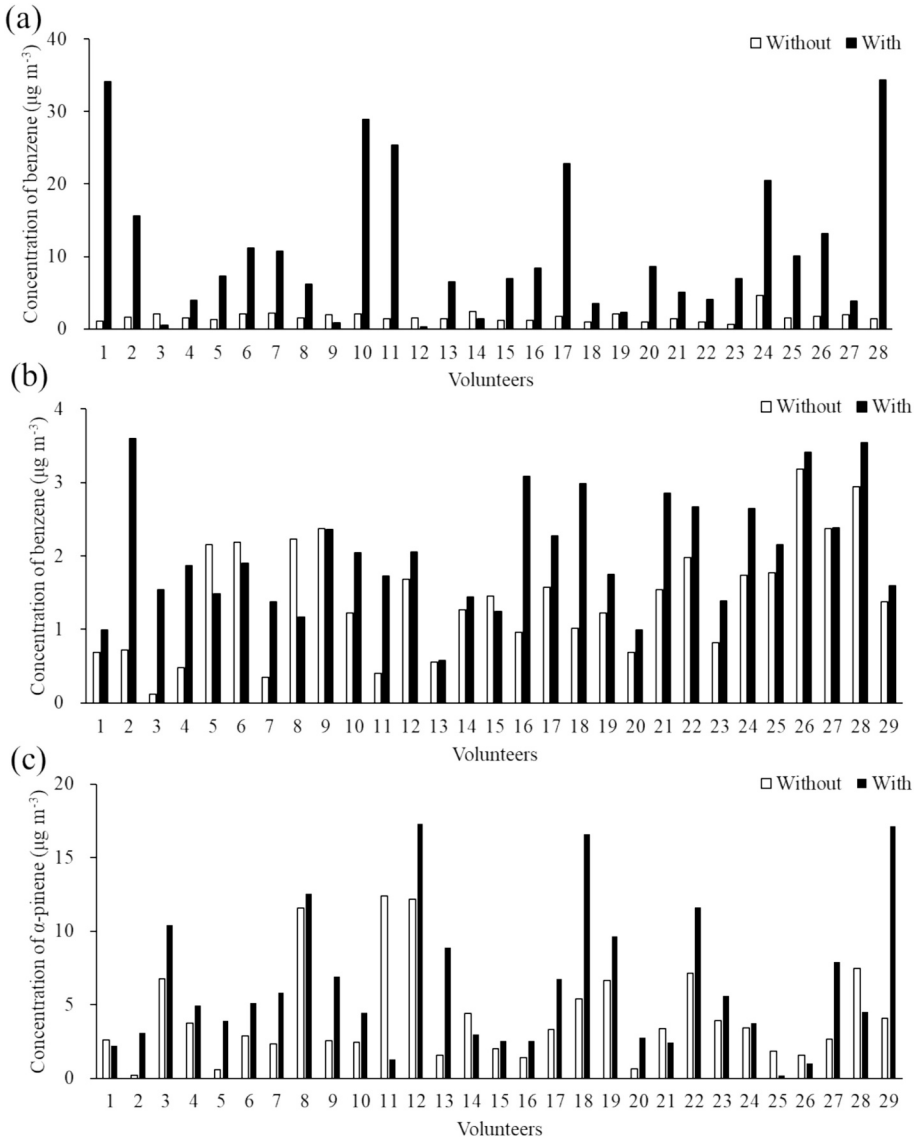


Fig. 3. Concentrations of benzene (μg m^{-3}) in studio apartments with and without using (a) coil and (b) mat types of mosquito repellents. Concentration of α-pinene in studio apartments with and without using (c) liquid type of mosquito repellent.

type mosquito repellents. Although all panels except for panel 28 ventilated the home while using coil-type mosquito repellents as usual, benzene concentrations increased averagely by a factor of 6.6 before its use. Personal exposure was measured for only 3 h in this study. Given that people spend approximately 90 % of their lifetime indoors (Robinson and Nelson, 1995) and typically utilize mosquito repellents for >3 h per day (Lu et al., 2020; MOE, 2016), the personal exposure to benzene from the use of coil-type mosquito repellents would be considerably high. For panel 28, the indoor air concentration of benzene was the highest at 34 μg m^{-3} after using a coil-type mosquito repellents without ventilation. The use of the coil-type mosquito repellents had a statistically significant effect only on benzene among the target VOCs, with a *p*-value of 0.000042 at the 95 % confidence level. For other VOCs, the increase in indoor concentrations was not statistically significant ($p > 0.05$). The differences in concentrations before and after product use were within a factor of 1.8.

The effect of deploying mat-type mosquito repellents was also statistically significant only for benzene among the target VOCs, the *p*-value of the paired sample *t*-test was 0.00041 at the 95 % confidence level. A statistically significant increase in benzene was observed in the residential apartments of 29 volunteers following the deployment of a mat-type mosquito repellent, as illustrated in Fig. 3(b). Although the mat-type mosquito repellents do not involve the direct burning process, the average benzene concentration increased by 1.4 times compared to before. All panels used mat-type mosquito repellents without ventilation. Generally, individuals use the mat-type mosquito repellents without adequate ventilation for periods exceeding 3 h. Consequently, their personal exposure to benzene may be greater than that measured in this study.

Using a liquid-type mosquito repellent increased average concentrations of α- pinene by a factor of 1.5 in residential apartments of 29 volunteers as shown in Fig. 3(c). The *p*-values of the paired sample *t*-test for α- pinene was lower than 0.010 at the 95 % confidence level. All panels used liquid-type mosquito repellents without ventilation. As people often use liquid-type mosquito repellents without proper ventilation for periods exceeding three hours, personal exposure to α- pinene may be higher than what was measured in this study. Terpenes including α-pinene are potential allergens, resulting in skin irritation, asthma, and chest tightness (Su et al., 2007; Wolkoff and Nielsen, 2017). Furthermore, terpenes react with oxidants like ozone and hydroxyl radicals producing secondary products that can be harmful (Carslaw, 2013; Huang et al., 2012; Nørgaard et al., 2014). Although the health hazards associated with exposure to terpenes should be much lower than those of benzene, secondary products that might form from reactions of terpenes could be an important health concern. Cautious use of liquid-type mosquito repellents is necessary especially because they are used without ventilation generally. For other VOCs, increase of indoor concentrations by using liquid-type mosquito repellent were not statistically significant ($p > 0.05$).

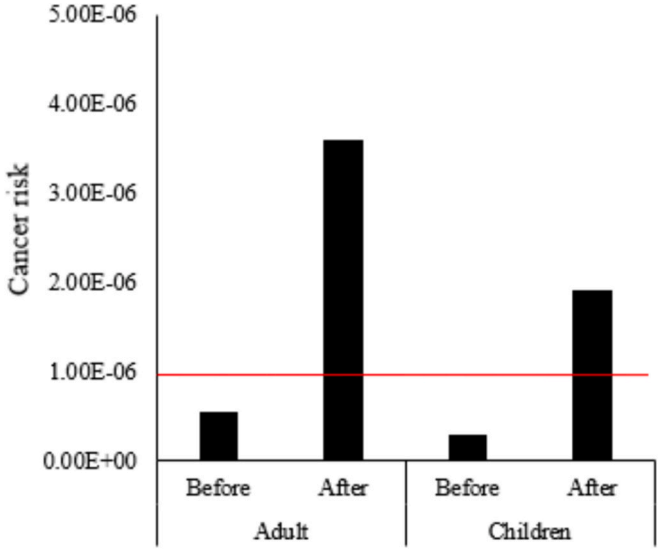


Fig. 4. The average cancer risks of benzene in studio apartments before and after using coil type of mosquito repellent.

3.3. Health risk assessment

The health risk assessment results are presented in Tables S5–S7. As illustrated in Fig. 4, the average incremental cancer risks for benzene were 10^{-6} to 10^{-4} for both adults and children following the use of coil-type mosquito repellent for 3.81 h. This indicates a low plausible hazard (NYS, 2012). Nevertheless, ATDSR (2022) suggests that at this level of risk, public education on exposure reduction strategies or ongoing monitoring may be considered, particularly if the pollutant can migrate and people can be exposed to greater levels. The average cancer risks for benzene after using coil-type mosquito repellent for 3.81 h increased by a factor of 6.6. Therefore, it is advisable to exercise caution when using this type of mosquito repellent, even with ventilation. The averages of cancer risks for benzene were 10^{-6} to 10^{-4} for adults after using mat-type mosquito repellents for 7.27 h, indicating a low plausible hazard. The 1.4 times increase of cancer risk for benzene indicates that the use of mat-type mosquito repellents has a much lower risk than coil-types even without ventilation. The increase in cancer risks for styrene was found to be insignificant after the use of three types of mosquito repellents. All mean values of HI for benzene, ethylbenzene, styrene, toluene, *p*-xylenes, o-xylene, and α-pinene were <1, indicating that the non-cancer risks are insignificant after the use of three types of mosquito repellents. However, as coil-type products may generate byproducts such as particulate matter or carbon monoxide from incomplete combustion, additional human health risks for them should be evaluated.

3.4. Estimation of indoor benzene after use of mat-type mosquito repellents

The steady-state concentrations of benzene in apartments after using mat-type mosquito repellent were also estimated using a mass balance equation, taking into account the pseudo-first order generation and elimination rates of benzene (VanLoon and Duffy, 2017). Assuming that the outdoor concentration of benzene is negligible and the emission rate ($R_{emission}$, μg h^{-1}) is constant during the use of a product, then Eq. (6) can be derived as follows:

$$C_g = \frac{R_{emission}}{Vk_e} + C_{in} \quad (6)$$

where C_g is the benzene gas phase concentration in air μg m^{-3}, k_e is defined as the elimination rate constant (1/h), C_{in} is the concentration of benzene in each space before the use of mat-type mosquito repellent (μg m^{-3}), V is the volume of the residential space in which the product used (m^3). It was assumed that air change was the dominant elimination process for benzene in apartments. The volumes of apartments were obtained via a survey of the volunteers. Volunteer 16 used the same commercial brand of mat-type mosquito repellent for which emission rate of benzene, 85 μg hr^{-1}, was measured in the chamber experiment. In a room of apartments, the geometric mean of the measured k_e values was 0.77 h^{-1} with a geometric standard deviation of 1.435 (Johnson et al., 2004). The volume of apartments for panel 16 was 23 m^3. Assuming steady-state, the calculated concentration of C_g for panel 16 was 5.7 μg m^{-3}. The measured value obtained through passive sampling was 3.1 μg m^{-3}. This suggests that the estimation was accurate, even if only in one instance. As shown in Fig. 5., on average, estimated value and measured value after the use of mat-type mosquito repellents were 6.6 and 2.0 μg m^{-3}, respectively. Except for volunteer 16, other 28

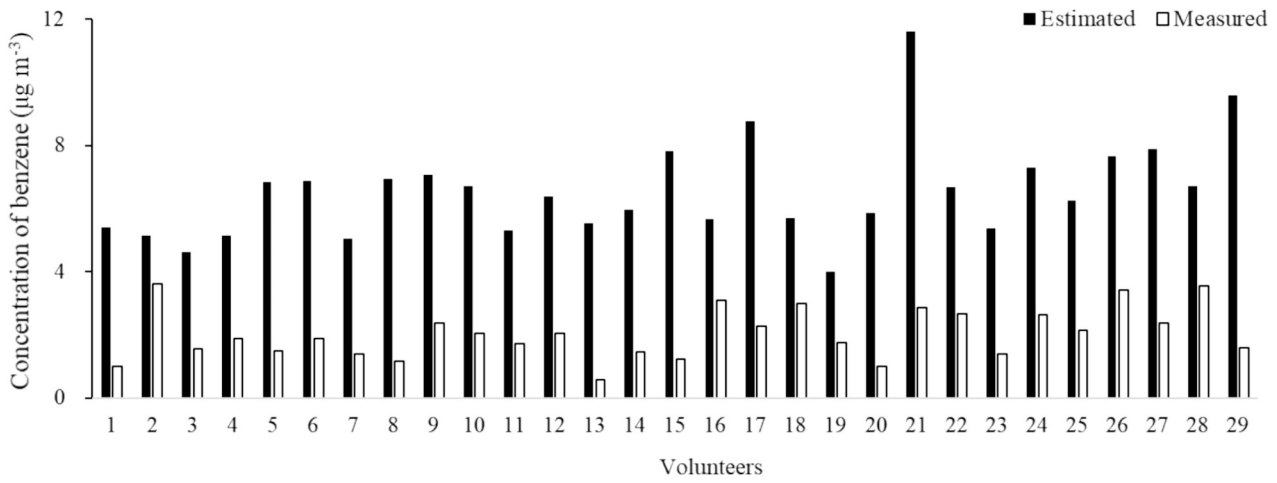


Fig. 5. Estimated and measured concentrations of benzene (μg m^{-3}) in studio apartments after using mat type of mosquito repellents.

volunteers used different brand of commercial products, which may have different emission rate of benzene. Insufficient time for reaching steady-state, 3 h, could be another reason for difference.

4. Conclusions

Including this study, previous studies have shown that using various types of mosquito repellents increases indoor VOCs. However, previous studies have been conducted in environmental chambers rather than in real living environments. This study investigated the effects of three typical types of mosquito repellents on the level of VOCs in living environment. Since personal exposure to target VOCs was measured only for 3 h in this study, the exposure level to those VOCs would be higher because they typically spend longer time in the apartment house. Despite all panels ventilated the place of use except for one panel, benzene concentrations increased by an average of 6.6 times compared to the background exposure after the habitual use of coil-type mosquito repellents. After the use of mat- and coil- types, the cancer risks of benzene significantly increased. Liquid-type mosquito repellents affected indoor α-pinene significantly. To prevent personal exposure to VOCs, it is necessary to use mosquito repellent more cautiously. Although the effects of mat- and liquid-type mosquito repellents on their living environments were relatively low, cautious use is still necessary because they are often used without ventilation exceeding 3 h.

CRediT authorship contribution statement

Pil-Gon Kim: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yun-Hee Choi:** Software, Investigation, Formal analysis, Data curation. **Arum Lee:** Investigation, Formal analysis, Data curation. **Jaeho Shin:** Investigation, Formal analysis, Data curation. **Eugene Song:** Writing – review & editing, Investigation, Funding acquisition, Formal analysis, Data curation. **Stefana Sochichiu:** Investigation, Formal analysis, Data curation. **Yerim Koo:** Investigation, Formal analysis, Data curation. **Yongseok Hong:** Writing – review & editing, Supervision. **Jung-Hwan Kwon:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2024.175158.

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