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Review Article

A Review on the Exposure to Benzene among Children in Schools, Preschools and Daycare Centres

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ABSTRACT Benzene, has been measured in indoor environments for many decades and has been identified to cause variety of health effects. As children spend most of their time indoors such as daycare centre, preschool and school, they are more likely to be exposed to indoor air pollutants. This paper was aimed to evaluate 15 years (2003–2018) of investigations of exposure to benzene among children within indoor environments from worldwide studies. Among 24 papers evaluated, the most frequently studied environment was in primary school (54%) and the highest concentration of benzene was found in preschool at 148.0 μg/m^3 in China. Benzene levels were found higher in indoors than outdoors for most of the studies. Active sampling techniques were used in 42% of studies that enable the determination of acute health effects on children during short-period of exposure time. Based on the papers evaluated in this study, most of the children are exposed to the inadequate environment during their time spent in indoor environments, which is not in compliance with the established standard of exposure to benzene and may lead to the increase of potential health risk. Besides, differences in sampling techniques and durations make it hard to compare the outcomes of the studies with health-effects guidelines. The evaluation from this study indicated a diversity of sampling approaches and techniques, pointing to the importance of establishment of standard method for collecting and reporting data, for both exposure and health effects.

KEY WORDS Benzene, Children's health effects, Daycare centre, Indoor air quality, Preschool, School

1. INTRODUCTION

Children spend most of their time in indoor environments, mainly at daycare centre, preschool and school. Indoor air quality refers to the air quality within buildings that will contributes to a favorable environment, a sense of comfort, health and well-being for occupants (USEPA, 2016). The levels of indoor pollutants are found to be two to five times higher than outdoors (Sousa *et al.*, 2012). Children are more likely to be exposed to indoor air pollutants as they spend most of their time indoors. The levels of indoor pollution and the duration of the exposure might have a considerable impact on children's health for the rest of their lives (Madureira *et al.*, 2012).

Volatile organic compounds (VOCs) such as benzene have been measured in indoor environments for many decades, and few studies on exposure to benzene among children have been reported (Norbäck *et al.*, 2017; Madureira *et al.*, 2015; Demirel *et al.*, 2014). Variety of health effects associated with benzene have been identified which includes possible childhood leukemia (Eden, 2010). Because of children are still developing, their bodies and their lungs breathe more air and their underdeveloped ability to communicate concerns in the response to air pollutant levels (ATSDR, 2015; USEPA, 2011).

There are many potential sources of benzene available in indoor environments such as attached garages in residential (Dodson *et al.*, 2008; Batterman *et al.*, 2007), occupants' activities like cleaning (Kim *et al.*, 2001), painting (Brown, 2002; Kim *et al.*, 2001), and tobacco smoke from smoking (Wallace, 1996; Wallace, 1989). Sometimes, indoor air can be originated from outdoors and provides a baseline for concentrations of benzene indoors, for example by climatic conditions and exchange of air through ventilation systems (WHO, 2010). Traffic sources (Kanjanasiranont *et al.*, 2017; Borgie *et al.*, 2014; Johnson *et al.*, 2007), petrol stations and certain industries related with coal, oil, natural gas, plastics, chemicals and steels (Jia *et al.*, 2008) have been related as sources of benzene outdoors.

This paper will discuss on the chemical properties, safe exposure limits, variety of sampling approaches and concentrations of benzene in indoor environments that have been reported by previous studies worldwide. Finally, this paper offers lessons and recommendations that can help to improve indoor air quality study.

1.1 Chemical Properties

Benzene (C_6H_6) with molecular weight 78.1 g/mol is an organic hydrocarbon (consists of carbon (C) and hydrogen (H) atoms) and an aromatic compound with a single six-member unsaturated carbon ring. It is a clear, colorless, volatile, highly flammable liquid with a characteristic odor and density of 874 kg/m^3 at 25°C. Benzene has a melting point of 5.5°C which is relatively low boiling point of 80.1°C at 1 atmosphere of pressure. It has a high vapor pressure which is 12.7 kPa at 25°C, causing it to evaporate rapidly at room temperature. It is slightly soluble in water (1.78 g/L at 25°C) and is miscible with most organic solvents (WHO, 2000). Benzene in air exists in the vapor phase, with residence times varying between 1–14 days, depends on the environment, climate and other pollutants concentration (WHO, 2010).

1.2 Safe Exposure Guidelines to Benzene

Standards and guidelines on safe exposure level of indoor air pollutants have been developed by government, professional health and safety organizations based on research and epidemiologic studies for many years. These are to ensure the best air quality inside a building for the occupants in order to control and minimize the potential health effect to occur in humans.

Regulatory guidelines for acceptable VOC concentrations within indoor environments do not currently exist in Malaysia. There is no safe level of benzene that can be recommended as benzene is a genotoxic carcinogen in humans (WHO, 2010). There is no reason that the guidelines for indoor air should differ from ambient air guidelines since the risk of toxicity from benzene inhalation is the same whether the exposure was indoors or outdoors. The geometric mean of the range estimates of excess lifetime cancer risk at concentration of 1 μg/m^3 is 6×10^{-6}. The concentrations of airborne benzene associated with lifetime cancer risk of 1/10 000, 1/100 000 and 1/1000 000 are 17, 1.7 and 0.17 μg/m^3, respectively (USEPA, 2011; WHO, 2010). OSHA set an exposure limit of 1 ppm in the workplace during an 8 hours working day and 40 hours working week. While, short-term exposure levels for 15 min are set at 5 ppm (OSHA, 1998).

2. METHODOLOGY

A comprehensive literature search was conducted to identify any studies on children of exposure to benzene within indoor environments conducted worldwide. Original research papers published in English language academic journals were obtained by searching electronic databases including from ScienceDirect, Scopus, ProQuest and Google Scholar. The keywords used in these searches were: 'benzene', 'exposure to benzene among children', 'school', 'daycare centre', 'indoor air quality', 'benzene in indoor environments', 'health effects benzene' and 'benzene guidelines'. The results were refined to identify the studies conducted from 2000 until 2018.

To be included in the evaluation, the selected studies needed to provide; (i) experimental data from sampling and analysis of benzene in indoor environments include daycare centre, preschool and school, (iii) be published as a journal, book chapter, or official government report. To summarize and compare concentrations of benzene data, a standard unit of μg/m^3 was chosen. Where parts per million (ppm) and milligram per meter cube (mg/m^3) were reported, these were converted to μg/m^3. In all cases, data were preserved in their original reported statistical format (i.e., arithmetic mean, median, min, max).

3. RESULTS

A total of 24 papers were evaluated in this study. Each paper reported one or more sampling locations, approaches, year of study and methods as presented in Table 1. Data for the concentrations of benzene in indoor environments that covered on studies conducted in schools, preschools and daycare centres have been evaluated in detail as shown in Table 2.

3.1 Country

Based on the papers selected as shown in Table 1, there were 15 countries that involved in determination of benzene in indoor environments. Generally, the highest number of studies that were conducted in these countries were included Portugal, United States of America, Turkey and Korea. The variation in the climate and location of each country worldwide, varies in temperature and humidity can significantly influence the indoor benzene levels.

3.2 Year and Focus of Study

The selection of the year was based on the date of publication since year 2000 until 2018. As shown in Table 1, earlier study was conducted in the year 2000 in two urban primary schools (Adgate *et al.*, 2004) and the recent study was conducted in the year 2014 (Mainka *et al.*, 2015) in two urban nursery school. However, the most recent study was published in the year 2018 by Villanueva *et al.* (2018) that covered 18 primary schools in urban, rural and industrial areas. Based on the list, study on exposure to benzene in children has become as one of the interesting topics to be investigated from across the countries from the last two decades.

3.3 Types of Indoor Environment

As referred to Table 1, the most frequently studied indoor environment was primary schools (54%), followed by daycare centres (31%) and preschools (15%). Most of the studies conducted in schools were focusing on the differences between the type of sampling areas, for example the differences between schools located in urban and suburban areas (Villanueva *et al.*, 2018; Demirel *et al.*, 2014; Pegas *et al.*, 2012; Sofuoglu *et al.*, 2011; Bartzis *et al.*, 2008; Godwin and Batterman, 2007; Adgate *et al.*, 2004). Meanwhile, as for the preschool and daycare centre, Yoon *et al.* (2011) and Mainka *et al.* (2015) also focused on the differences between sampling areas. However, the other studies did not mention clearly the exact location of the sampling sites (i.e. city, urban, suburban, rural, industrial areas).

3.4 Sampling Methods

Based on Table 1, the sampling methods of the studies were varying by approach, time, flow rate, number of sampling sites and sampling techniques. Active sampling requires a pump whereas passive sampling is through diffusion controlled (Goodman *et al.*, 2017). For the exposure assessment of benzene, active and passive samplings were used at almost equal percentages; 58% for passive sampling and 42% for active sampling of all studies. Passive sampling generally used single sorbent due to the lower diffusion-controlled sorbent adsorption rates. Radiello passive sampler (RAD 130, activated charcoal), Summa™ canister passive samplers and 3M OVM 3500 organic vapor monitors were used in passive sampling. Meanwhile, active sampling techniques were included the used of charcoal and thermal desorption tubes; i.e. Anasorb Coconut Shell Charcoal tubes and Tenax TA thermal desorption tubes. Active sampling technique was used in studies that collect sufficient volumes of air in shorter time periods, as low as 30 minutes (Norbäck *et al.*, 2017; Sofuoglu *et al.*, 2011; Jang *et al.*, 2007).

3.5 Sampling Duration

There were variations of sampling duration in the studies of exposure to benzene based on Table 1. Most of the papers had a sampling time more than 4 hours per day (Axelrad *et al.*, 2013; Bureau, 2011). Few studies had sampling duration of 24 hours for 5 days per week (Kalimeri *et al.*, 2016; Madureira *et al.*, 2015; Demirel *et al.*, 2014; Zhang *et al.*, 2013; Pekey and Arslanbaş, 2008), 7 days per week (Villanueva *et al.*, 2018; Geiss *et al.*, 2011; Bartzis *et al.*, 2008) and less than 6 hours per

Table 1. Sampling approaches in determination of benzene in indoor environments.

Ref.	Year of study	Study area	No. of study site	Exposure duration	Flow rate	Sampling method	Location (month/season)
Villanueva *et al.* (2018)	2013	School	Urban = 6 Rural = 6 Industrial = 6	2 weeks	–	Radiello passive sampler (RAD 130, activated charcoal)	Spain (Feb–Apr)
Norbäck *et al.* (2017)	2007	School	8	4 h/7 days	0.2 L/min	Anasorb 747 charcoal tubes	Malaysia (n/a)
Kalimeri *et al.* (2016)	2011–2012	School	2	5 days/week	–	Radiello passive samplers	Greece (Sept–Oct/non-heating; Jan–Feb/heating period)
Madureira *et al.* (2015)	2011–2013	School	20	24 h/5 days	–	Tenax TA thermal desorption tubes	Portugal (Nov–March/winter)
Demirel *et al.* (2014)	2009	School	Urban = 1 Suburban = 1	24 hours	–	3M OVM 3500 organic vapor monitors	Turkey (March/winter)
Pegas *et al.* (2012)	2010	School	Urban = 1 Suburban = 1	5 days/week	–	Radiello passive samplers	Portugal (April–June)
Madureira *et al.* (2012)	2011	School	2	24 h/5 days	–	Tenax TA thermal desorption tubes	Portugal (Nov/summer)
Geiss *et al.* (2011)	2003–2008	School	22	7 d/week	–	Radiello passive samplers (RAD 130, activated charcoal)	European cities (summer, winter)
Sofuoglu *et al.* (2011)	–	School	Urban = 2 Suburban = 1	5 hours	66.7 mL/min	Tenax TA sorbent tubes active sampler	Turkey (winter, spring, fall)
Pekey & Arslanbaş (2008)	2006–2007	School	3	24 hours	–	Radiello passive samplers activated charcoal (Carbograph 4)	Turkey (May–June/summer; Dec–Jan/winter)
Bartzis *et al.* (2008)	2007	School	Urban = 1 Suburban = 1	1 week	–	Radiello passive sampler (RAD 130, activated charcoal)	Mediterranean cities (winter)
Godwin & Batterman (2007)	2003	School	Suburban = 9	4.5-day	–	Tenax GR thermal desorption adsorbents	USA (March–June/spring, early summer)
Adgate *et al.* (2004)	2000	School	Urban = 2	31 h/5 days	–	3M OVM 3520 organic vapor monitors	USA (Jan–Feb/winter; Apr–May/spring)
Guo *et al.* (2003)	–	School	6	1 hour; 8 hours	0.0931 L/min; 0.0121 L/min	Summa™ canister passive samplers	Hong Kong (n/a)
Kalimeri *et al.* (2016)	2011–2012	Preschool	1	5 days/week	–	Radiello passive samplers	Greece (Sept–Oct/non-heating; Jan–Feb/heating period)
Zhang *et al.* (2013)	2011	Preschool	8	24 hours	–	Passive sampler	China (March–April)
Yoon *et al.* (2011)	–	Preschool	Urban = 13 Suburban = 4	60–100 min	0.07–0.1 L/min	Tenax TA thermal desorption tube	Korea (n/a)
Geiss *et al.* (2011)	2003–2008	Preschool	22	7 days/week	–	Radiello passive sampler (RAD 130, activated charcoal)	European cities (n/a)
Hwang *et al.* (2017)	2012	Daycare centre	25	7 hours	100 mL/min	2,4-DNPH coated Florisil thermal desorption cartridge	Korea (May–July)
Noguchi *et al.* (2016)	–	Daycare centre	1	1 hour	100 mL/min^{-1}	Tenax TA thermal desorption tube and Carboxen 1000 60/80	Japan (Dec, March)
Quirós-Alcalá *et al.* (2016)	2013	Daycare centre	14	10 hours	1 L/min	SKC Anasorb Coconut Shell Charcoal tubes	Columbia (Autumn)
St-Jean *et al.* (2012)	2008	Daycare centre	21	6 hours	13.5 mL/min	Summa™ canister passive samplers	Canada (Jan–Feb/winter)
Roda *et al.* (2011)	–	Daycare centre	28	5 days/week	–	Radiello passive sampler (RAD 130, activated charcoal)	France (Oct–Mar/winter; Apr–Sept/summer)
Zuraimi *et al.* (2003)	–	Daycare centre	104	9 hours	5 and 10 mL/min^{-1}	Tenax TA thermal desorption tube	Singapore (n/a)
Jang *et al.* (2007)	2006	Daycare centre	29	30 min	–	Tenax TA thermal desorption tube	Korea (Jan–Dec)
Mainka *et al.* (2015)	2013–2014	Daycare centre	Urban = 2	–	–	Tenax TA thermal desorption tube	Poland (Dec–Jan/winter)

n/a: not available; h: hour; d: day; L/min: liter/minute; mL/min: milliliter/minute

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day (Norbäck *et al.*, 2017; Noguchi *et al.*, 2016; St-Jean *et al.*, 2012; Sofuoglu *et al.*, 2011; Yoon *et al.*, 2011; Godwin and Batterman, 2007; Jang *et al.*, 2007). Due to their differ in sampling durations comparison between these studies were limited.

However, some studies had reported the same sampling durations of 24-hours period. For example, five studies were conducted in indoors with the presence of children and the range mean values were reported as followed: 1.5–2.7 μg/m^3 (Madureira *et al.*, 2015); 0.39–13.2 μg/m^3 (Demirel *et al.*, 2014); 2.5–148.0 μg/m^3 (Zhang *et al.*, 2013); $<$1.0–1.63 μg/m^3 (Madureira *et al.*, 2012) and 7.5–19.77 μg/m^3 (Pekey and Arslanbaş, 2008). Meanwhile, the other studies were reported in varieties of sampling durations from 30 minutes (Jang *et al.*, 2007) to 7 days per week.

3.6 Analytical Methods

Analytical method protocol used by most of the authors in their studies had cited US EPA Compendium Method TO-17 for the analysis of benzene (Norbäck *et al.*, 2017; Quirós-Alcalá *et al.*, 2016). All studies reported to use gas chromatography/mass spectrometry (GC/MS) as the principal method of analysis. Meanwhile, automated thermal desorption GC/MS and flame ionization detector were used as the principal mode of detection, however they were not uniformly specified in every study. In general, the methods used for analyzing benzene in indoor environments are consistent with international protocol.

3.7 Concentrations of Benzene

For the details on the concentrations of benzene, the indoor arithmetic mean (AM), median, minimum (min) and maximum (max) concentrations are reported in Table 2. The min, max and median values were reported only in some studies and the AM values were reported in all the selected studies. In the comparison on benzene levels among the studies, the differences in sampling approach and duration were not considered. Thus, the evaluation in this study is provided with that following criteria (Goodman *et al.*, 2017).

Based on Table 2, the maximum concentration of benzene in school was recorded at 19.77 μg/m^3 which was found during winter season (Pekey and Arslanbaş, 2008). The study concluded that the indoor activity, ventilation and the duration of human occupancy during the winter season had influenced the indoor air quality in the building. High level of air pollutant during winter season was due to the decrease in ventilation since windows were opened less frequently and air conditioners were seldom used, resulted in persistent benzene sources from indoors. Meanwhile, the highest concentration of benzene reported in preschool in Nanjing, China at 148.0 μg/m^3 (Zhang *et al.*, 2013). However, the explanation on the level of benzene recorded in this study was not reported. As for the benzene concentration in daycare centre, the maximum value was found at 32.7 μg/m^3 (Zuraimi and Tham, 2008). This study was conducted to identify the effects of ventilation strategies on VOCs in 104 daycare centres in Singapore. Based on the source factor analysis, benzene was loaded together with compounds dominantly associated with traffic emissions from outdoor and can be emitted from indoor sources and human related activities (Sax *et al.*, 2004; Zuraimi *et al.*, 2003).

3.8 Indoor to Outdoor (I/O) Ratio

Based on Table 2, 56% of studies reported I/O ratios and 44% did not reported on the I/O ratios. This is because there were no available data on the outdoor air measurements. I/O ratios that were $\leq$1 indicate the absence of indoor sources or dilution effects of indoor sources. While ratios that were $>$1 indicate strong indoor sources or poor ventilation (Zuraimi *et al.*, 2008, 2003). Few of the studies evaluated the I/O ratio based on each study site (Villanueva *et al.*, 2018; Kalimeri *et al.*, 2016; Demirel *et al.*, 2014; Yoon *et al.*, 2011; Pekey and Arslanbaş, 2008) and some studies reported I/O ratios generally.

Generally, I/O ratios in the range of 1.1–3.3 revealed that much of benzene sampled were several times higher in indoors compared to the outdoors. Meanwhile, the I/O ratios ranged from 0.61 to 1.0 indicated strong outdoor sources of benzene. The lowest I/O ratio at 0.61 was reported by Guo *et al.* (2003) due to the motor vehicle emission as the significant outdoor benzene source. The highest I/O ratio at 3.3 was found during summer season in preschool by Kalimeri *et al.* (2016). The study found that the source of benzene was detected from the wall paint in the building.

3.9 Seasonal Variation

Many studies had reported on the effects of the seasonal variations during the sampling were conducted. These variety of the seasons had influenced the concen-

Table 2. Concentrations of benzene in indoor environments (μg/m^3).

Ref.	No of sample	Benzene (μg/m^3)				I/O ratio
		AM	Median	Min	Max	
Villanueva *et al.* (2018)	54	S1: 0.5 S2: 0.3 S3: 0.7	S1: 0.48 S2: 0.27 S3: 0.66	S1: 0.4 S2: 0.2 S3: 0.6	S1: 0.5 S2: 0.4 S3: 0.9	S1: 0.9 S2: 1.0 S3: 0.8
Norbäck *et al.* (2017)	32	7.2	4.6	–	31.7	0.93
Kalimeri *et al.* (2016)	–	S1: 1.5[a]; 3.7[b] S2: 1.5[a]; 4.0[b]	–	–	–	S1: 1.7[a]; 1.2[b] S2: 1.5[a]; 1.7[b]
Madureira *et al.* (2015)	73	–	2.5	1.5	2.7	0.84
Demirel *et al.* (2014)	S1: 26 S2: 24	S1: 1.91 S2: 2.71	S1: 0.92 S2: 2.50	S1: 0.39 S2: 1.54	S1: 13.2 S2: 4.74	S1: 1.10 S2: 0.70
Pegas *et al.* (2012)	–	0.31	–	–	–	0.84
Madureira *et al.* (2012)	–	S1: <1.0 S2: 1.63	–	–	–	–
Sofuoglu *et al.* (2011)	–	10.4	–	–	–	–
Pekey *et al.* (2008)	–	7.5[a] 19.77[b]	–	–	–	1.57[a] 1.20[b]
Bartzis *et al.* (2008)	–	S1: 2.4 S2: 4.5	–	–	–	n/d
Godwin *et al.* (2007)	64	0.09	–	–	1.6	1.4
Adgate *et al.* (2004)	113	–	0.6[b] 0.6[c]	–	–	–
Guo *et al.* (2003)	24	3.04	0.86	0.68	12.22	0.61
Kalimeri *et al.* (2016)	–	1.4[a]; 3.7[b]	–	–	–	3.3[a]; 2.0[b]
Zhang *et al.* (2013)	–	P1: 2.5 P2: 6.0 P3: 148.0 P4: 2.5 P5: 3.5 P6: 30.0 P7: 22.5 P8: 11.5	–	–	–	–
Yoon *et al.* (2011)	P1: 54 P2: 17	P1: 9.24 P2: 4.98	–	P1: 2.0 P2: 2.0	P1: 33.18 P2: 12.71	P1: 1.18 P2: 0.83
Geiss *et al.* (2011)	188	4.4	2.6	0.5	63.7	1.2
Hwang *et al.* (2017)	–	1.2[d] 1.7[e]	1.2[d] 1.7[e]	0.4[d] 0.8[e]	6.8[d] 7.9[e]	1.09
Noguchi *et al.* (2016)	–	A: 10.3; 1.29 B: 8.2; <0.2 C: 6.2; <0.2	–	–	–	–
Quirós-Alcalá *et al.* (2016)	35	2.0	–	<LOD	4.4	–
St-Jean *et al.* (2012)	21	1.8	–	0.9	6.3	–
Roda *et al.* (2011)	–	1.4; 1.6[a] 2.0; 2.1[b]	1.4; 1.6[b] 2.1; 2.1[c]	0.5; 0.9[b] 0.5; 0.9[c]	3.7; 3.9[b] 4.4; 4.5[c]	–
Zuraimi *et al.* (2008)	123	NV: 25.4 HB: 17.5 ACMV: 24.2 AC: 17.9	NV: 32.7 HB: 30.5 ACMV: 28.4 AC: 21.2	–	–	–
Jang *et al.* (2007)	183	4.2	3.6	n/d	13.1	2.2
Mainka *et al.* (2015)	24	S1: 1.63; 2.93 S2: 2.59; 2.11	–	–	–	–

AM: Arithmetic mean; I/O: Indoor/Outdoor; S: school; n/d: not detectable; a summer; b winter; c spring; d day; e night; P: preschool; LOD: limit of detection; NV: natural ventilation; HB: hybrid ventilation; ACMV: air-conditioned and mechanically ventilated; AC: air-conditioned

trations of benzene in indoor environments (Kalimeri *et al.*, 2016; Madureira *et al.*, 2015). 44% of the studies did not reported on the type of season, 28% were reported on the benzene levels from a single season, 24% were recorded in two seasons (winter/summer; spring/summer; winter/spring) and only one study that reported in three seasons (winter/spring/autumn) (Sofuoglu *et al.*, 2011).

Based on the studies that were conducted within two seasons, concentrations of benzene were found to be higher in indoors during winter season as compared to the warmth season (Kalimeri *et al.*, 2016; Geiss *et al.*, 2011; Roda *et al.*, 2011; Pekey and Arslanbaş, 2008; Godwin and Batterman, 2007). This might be due to the low ventilation rate as air conditioners are seldom used and short window opening periods with low opening frequency had increased the benzene levels (Kalimeri *et al.*, 2016). Besides that, indoor activity, sources of benzene indoors and duration of human occupancy also influenced the indoor air quality during winter (Pekey and Arslanbaş, 2008).

4. DISCUSSION

This evaluation of benzene exposure among children in indoor environments based on 24 studies from the past 15 years revealed that there is no specific regulation and standard for indoor air quality that have been reported. Comparisons among the studies are made without the consideration of the sampling methods. In general, the sampling durations were found to be different in most of the studies. This is rarely being acknowledged and is a problem for researchers globally who wish to compare their findings with previous studies. This paper indicates the need for a standard approach especially in data collection, sampling method and the correct way on how to report data.

The evaluation also showed that results on benzene concentrations from some investigations were found to be higher as compared to US Environmental Protection Agency (USEPA, 2009) (RfC: 0.009 ppm/0.5 ppm for 8-hour), Occupational Safety and Health Administration (OSHA, 1998) (1 ppm for 8-hour/5 ppm for 15-minute) and World Health Organization (WHO, 2010) with no safe exposure level health-based guidelines. However, the used of passive sampling in 58% of studies limits the determination of concentrations relevant to short-term exposure and guidelines for acute effects. Meanwhile, another 42% of studies used active sampling in their assessment. This may indicate better support on determination of acute health effects of exposure to benzene in children. Sampling methods and more consistent time periods with exposure guidelines, as well as more compatible pollutant exposure guidelines with sampling patterns and occupant behavior, would enable a more rigorous assessment. Besides, comparison of potential health risks also can be made.

This paper also found most of the studies were conducted in school environments and only 15% were conducted in preschools and 31% for daycare centres. The highest level of benzene was found in preschools at 143.0 μg/m^3 (Zhang *et al.*, 2013). This result indicated that some preschool environments may be a significant source of benzene exposure. Thus, it is important to increase the number of studies in preschool in the future. Furthermore, children in preschools and daycare centres may be more vulnerable to the effects of benzene exposures as compared to the children in schools. Thus, determination of exposure to air pollutants in these environments is especially important to the children.

The results on the concentrations of benzene as shown in Table 2 also indicated the increase of potential health risk to these children. A study by Rumchev *et al.* (2004) suggested that children exposed to benzene at levels of $\geq$20 μg/m^3 were eight times more likely to have asthma. Duarte-Davidson *et al.* (2001) concluded that the evidence from human studies suggests that any risk of leukemia to infants and children who may be exposed continuously to concentrations of benzene at 3.4 μg/m^3 to 5.7 μg/m^3. However, there is no known exposure threshold for the risks of benzene exposure. Therefore, it is expedient to reduce indoor exposure levels to as low as possible. This will require the occupants to reduce or eliminate human activities indoors that may release benzene, such as using building materials that off-gas benzene. Providing an adequate ventilation methods in a building like in modern building located near heavy traffic or other major outdoor sources of benzene, would be beneficial for the occupants, especially children (WHO, 2010).

Other than that, the most recent study conducted in educational environment that involved young children was conducted in 2018 in different spatial characteristics, which only one study in school (Villanueva *et al.*, 2018). Overall, only few studies that reported on the locations of the sampling sites. Based on the evaluated studies, high significant levels of benzene have been related to the study areas in urban and industrial, compared to in rural area. Thus it is important to acknowledge that difference in the spatial variation also can influence the benzene concentrations in indoor environments.

5. CONCLUSIONS

In summary, study related to benzene exposure in educational environments among children has evolved from the early year of 2000 up until recent study in 2018. Concentrations of benzene were found to be higher indoors than outdoors, especially in buildings located in urban and industrial areas, and during cold season. In some cases, these concentrations were exceeded the exposure guidelines proposed by US EPA, OSHA and WHO. Based on the papers evaluated in this study, most of the children were exposed to the inadequate environment during their time spent in indoor environments, which is not in compliance with the established standard of exposure to benzene and may lead to the increase of potential health risk such as asthma and cancer risk. To enable more valid comparison among studies with exposure guidelines, a standard approach for sampling and correct way on reporting data should be introduced. Finally, greater attention should be focused on indoor air quality studies that related to air pollutants such as benzene which are underreported and with vulnerable populations like children and elderly. Health and environmental pollution follow-up system should be developed in every country to monitor and identify the source and health effects of air pollutants.

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CONFLICT OF INTEREST

Authors state no conflict of interest.

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