Predictors of indoor BTEX concentrations in Canadian residences

by Amanda J. Wheeler, Suzy L. Wong, Cheryl Khoury and Jiping Zhu

Abstract

Background

Benzene, toluene, ethylbenzene and *m-, p*-xylenes and *o*-xylene (BTEX) are a group of volatile organic compounds that originate from similar sources. Given the potentially negative health implications of BTEX exposure and their prevalence in residential indoor air, it is important to understand typical residential concentrations and identify predictors.

Data and methods

The 2009 to 2011 Canadian Health Measures Survey included an indoor air component. Questionnaires were administered, and respondents were asked to deploy an air sampler in their home for 7 consecutive days. This analysis is based on BTEX data from 5,191 respondents. Mean BTEX concentrations were examined overall, and by dwelling type and garage configuration. Stepwise regression models were used to examine potential sources of BTEX components.

Results

Means were 1.95 μg/m^3 (benzene), 19.17 μg/m^3 (toluene), 4.09 μg/m^3 (ethylbenzene), 14.42 μg/m^3 (*m- ,p*-xylenes), and 4.16 μg/m^3 (*o*-xylene). Significant predictors of the presence of BTEX included a garage on the property, regular smoking in the home, renovations in the past month, number of occupants, use of paint remover, and use of fragrance.

Interpretation

Results of this nationally representative study found that BTEX concentrations are relatively low among Canadian residences, and identified several different indoor sources.

Keywords

Benzene, indoor air quality, toluene, volatile organic compounds, xylenes

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Benzene, toluene, ethylbenzene, *m-, p*-xylenes and *o*-xylene (BTEX) are a group of Volatile Organic Compounds (VOCs). Indoor sources include paints, cigarette smoke and building materials. As well, vehicle combustion gases and evaporative emissions can migrate from attached garages. These VOCs are ubiquitous in residential settings, with exposures 2 to 100 times higher indoors than outside.[1,2]

Health effects depend on whether BTEX exposures are acute or chronic. Acute effects (for example, dizziness, tremors, eye, nose and throat irritation) are observed in humans only after exposure to very high levels not typically found in residential environments.[3,4] However, chronic exposures to lower concentrations may also result in adverse health effects. Benzene is a known carcinogen, which, in occupational studies, has been shown to cause leukemia in humans.[5] In addition to effects on hearing and kidneys, ethylbenzene has been reported to cause lung tumours in animals exposed to high concentrations over many weeks.[6] High long-term exposure of animals to toluene and the xylenes can affect their central nervous system.[3,4]

Few jurisdictions have developed indoor air guidelines. The Health Canada long-term residential indoor air quality guideline for toluene[4] (2,300 μg/m^3) falls within the range of values (not all specific to indoor air) set by other recognized international organizations (300 to 5,000 μg/m^3).[7-10] No Canadian indoor air guidelines are available for other BTEX components. The European Commission, however, has taken decisions on benzene (to reduce levels to as low as reasonably achievable) and on the xylenes (setting a long-term indoor exposure limit equal to 200 μg/m^3). The World Health Organization (WHO)[11] has published guidelines for a number of indoor air pollutants including benzene, for which it recommends that levels be reduced to as low as possible. The WHO estimates that the concentration of benzene associated with a 1 in 100,000 risk of leukemia is 1.7 μg/m^3. Published reference concentrations for ethylbenzene, which are not specific to indoor air, range from 200 to 2,000 μg/m^3, depending on the critical effect on which the value is based.[6,12,13]

Given the potential health implications of exposure to the BTEX components, it is important to determine levels in residential indoor air and to identify sources. This study is based on data from Statistics Canada's 2009 to 2011 Canadian Health Measures Survey (CHMS),[14] which produced nationally representative estimates of levels of 84 VOCs, including the BTEX components.

Data and methods

The CHMS is an ongoing survey designed to provide direct health measures data at the national level.[14] The 2009 to 2011 CHMS comprised participants from the Canadian population aged 3 to 79 in private households. Residents of First Nations Reserves or other Aboriginal settlements, institutions and some remote regions, and full-time members of the Canadian Forces were excluded. More than 96% of the population was represented.[15] Ethics approval for the CHMS was obtained from Health Canada's Research Ethics Board.[16]

Data were collected at 18 sites across the country from August 2009 through November 2011. The survey consisted of a questionnaire administered in the respondent's home, followed by a visit to a mobile examination centre where physical measures were performed, and additional questionnaires were administered. Participation was voluntary; respondents could opt out or refuse any part of the survey at any time. Written informed consent was obtained from respondents aged 14 or older. For younger children, a parent or legal guardian provided written consent, in addition to written assent from the child (where possible). Details about the survey can be found in the *Canadian Health Measures Survey Data User Guide: Cycle 2*,[15] and details about the indoor air component can be found in a companion *Health Reports* paper.[17]

Of the households selected for the CHMS, 75.9% agreed to participate. In each responding household, one or two members were selected; 90.5% of selected household members completed

Text table 1
Questions from 2009 to 2011 Canadian Health Measures Survey used to derive predictor variables, and categorization used in stepwise regression analyses

Question	Derived category
What type of dwelling do you live in?	Single detached, double, row, duplex
	Low-rise apartment, high-rise apartment, institution, hotel, rooming/lodging house, camp, mobile home, other
Do you have a garage on your property? *	Yes/No
In the past month, have you or anyone else ever smelled fumes in your home from cars, trucks or other vehicles?	Yes/No
In the past month, have you had a major home renovation?	Yes/No
In the past month, have new carpeting or rugs been installed in your home?	Yes/No
In the past week, which of the following products did you or anyone else use inside your home?	Gasoline or gasoline-powered devices (Yes/No)
	Kerosene (Yes/No)
	Moth balls or crystals (Yes/No)
	Paint (Yes/No)
	Paint remover (Yes/No)
	Solvents (Yes/No)
	Candles (Yes/No)
	Stain (Yes/No)
On a typical day over the past week, did you normally open windows or doors to get fresh air into your home?	Yes/No
How old is this home? (years)	Less than 20
	20 to 39
	40 or more
Excluding the basement and garage, what is the approximate area of this home? (square feet)	1,000 or less
	1,001 to 3,000
	3,001 or more
What is the main heating source in this home?	Oil furnace (Yes/No)
	Gas furnace (Yes/No)
	Electric heat (Yes/No)
	Wood-burning stove (Yes/No)
	Wood-burning fireplace (Yes/No)
	Gas fireplace (Yes/No)
What is the total number of people living here?	One
	More than one
Including household members and regular visitors, does anyone smoke inside this home every day or almost every day?	Yes/No
In the past 3 months, have you done any of the following in your leisure time or at school?	Arts (Yes/No)
	Model-making (Yes/No)
	Auto repairs (Yes/No)
	Refinishing furniture (Yes/No)
	Woodworking (Yes/No)
In the past 24 hours, have you used any of the following?	Fragrance (Yes/No)
	Hairstyling products (Yes/No)

*only respondents who reported living in a single-detached home, double, row or terrace home, or duplex the household questionnaire, and 81.7% of the responding household members participated in the subsequent physical measures component at the mobile examination centre, where one respondent per dwelling was given an indoor air sampler to deploy in their home. Valid indoor air data were collected from 81.9% of mobile examination centre participants. The final response rate was 46.0% (75.9% for selected household x 90.5% for selected person x 81.7% for mobile examination centre visit x 81.9% for valid indoor air data). The analyses in this article are based on 5,191 respondents from 3,857 residences, for which valid indoor air data were collected.

Indoor air samples of VOCs were collected using the PerkinElmer Thermal Desorption Sorbent Tube (Part No. N9307002, PerkinElmer, Inc., Shelton, CT, USA). VOC uptake rates in the tube were previously estimated through a passive and active co-location experiment.[18] At the mobile examination centre, a questionnaire about characteristics of the home and the presence and use of potential sources of VOCs was administered, and respondents were instructed on handling of the samplers. They were asked to deploy the sampler in their living or family room at least 1.5 meters above the floor for 7 consecutive days, beginning the morning after their appointment at the mobile examination centre. They were asked to return the sampler to the testing laboratory at the end of the 7-day period using a pre-paid envelope. The samplers were analyzed using a PerkinElmer thermal desorber (Model: ATD650) and an Agilent gas chromatograph (Model: 6890) interfaced with an Agilent mass spectrometer (Model: 5975N) (Agilent Inc., Santa Clara, CA, USA).[18]

If two respondents were from the same household, one of them was selected to participate in the indoor air component. The indoor air results (sampler and questionnaire data) were applied to both respondents. Each of the 5,191 respondents has a corresponding set of VOC data from the air sampler that was deployed in their home. Survey weights were applied so that the results from these respondents would be nationally representative of Canada.

Each respondent answered the household questionnaire, which included personal behavioural characteristics such as participation in leisure-time activities and the use of fragrance and hairstyling products. Several questions were identified *a priori* as potential predictors of indoor air levels (Text table 1).

A total of 173 field blanks, 74 travel blanks and 79 pairs of duplicates were evaluated. More than 50% of the field blanks for benzene, ethylbenzene and *o*-xylene had values greater than the laboratory limit of detection. Data for these VOC components were blank corrected by subtracting the median value of the field blanks. Details about the blank correction procedure and results of the blanks and duplicates are available in the companion *Health Reports* article.[17]

For the statistical analyses, VOC results below the laboratory limit of detection (LOD) were replaced with a value of ½ LOD. The arithmetic mean, geometric mean, and percentile distributions were calculated for each pollutant. Descriptive statistics and statistical differences were also calculated for the BTEX components by dwelling type and garage configuration. Associations between BTEX components were evaluated using Pearson correlations. The relationship between BTEX components and the selected *a priori* potential predictors was evaluated using regression analyses. Distributions of the BTEX components were positively skewed and were log-normally transformed for all regression analyses. Univariate regressions were performed for each BTEX component and each predictor. Marginally significant predictors ($p<0.10$) in the univariate analyses were considered for inclusion in a stepwise regression model ($p<0.10$ to enter and $p<0.10$ to remain). Regression results and 95% confidence intervals were expressed as relative (percentage) change in BTEX concentrations associated with a given change in the predictor, calculated as $100x(\exp^{\beta}-1)$, where β is the regression coefficient from the model with log BTEX concentrations as the outcome.

All estimates were based on weighted data at the person level. Statistical analyses were performed using SAS and SUDAAN software. Standard errors, coefficients of variation and 95% confidence intervals were calculated with the bootstrap technique.[19,20] The number of degrees of freedom was specified as 13 to account for the CHMS sample design.[15] Significance levels were set at $p<0.05$.

Results

Data description

Descriptive statistics of the BTEX components (where X represents *m-, p*-xylenes and *o*-xylene separately) are presented in Table 1. More than 99% of the samples were above the limit of detection for each component. The means and 10th to 95th percentiles were 1.95 μg/m³ (0.33 to 7.42) for benzene; 19.17 μg/m³ (2.28 to 73.60) for toluene; 4.09 μg/m³ (0.36 to 15.07) for ethylben-

Table 1
Residential indoor air concentrations (μg/m³) of BTEX components, household population aged 3 to 79, Canada, 2009 to 2011

BTEX component	% less than LOD	Mean	Geometric mean	Percentile 10th	25th	50th	75th	90th	95th
Benzene	0.27	1.95	1.07	0.33	0.51	0.90	2.07	4.24	7.42
Toluene	0.04	19.17	8.34	2.28	3.63	7.01	16.08	37.23	73.60
Ethylbenzene	0.04	4.09	1.44	0.36	0.60	1.24	2.78	7.28	15.07
m-, p-Xylenes	0.08	14.42	5.15	1.28	2.05	4.26	10.61	28.47	59.90
o-Xylenes	0.04	4.16	1.50	0.37	0.62	1.24	3.04	8.16	16.56

LOD = limit of detection
Source: 2009 to 2011 Canadian Health Measures Survey.

zene; 14.42 µg/m³ (1.28 to 59.90) for *m-, p*-xylenes; and 4.16 µg/m³ (0.37 to 16.56) for *o*-xylene. All toluene values were below the Health Canada indoor air guideline value of 2,300 µg/m³.

Pearson correlations between the BTEX components showed that the strongest associations were between ethylbenzene, *m-, p*-xylenes and *o*-xylene (all greater than r=0.87; data not shown). Benzene and toluene were moderately correlated with each other and with the other BTEX components (r=0.31 to 0.52).

Predictors of exposure

Based on the *a priori* predictors in the literature, corresponding CHMS questions were used to identify potential sources of the BTEX components. Univariate regressions were used to determine predictors to include in the final model (data not shown). Final stepwise regression model results are presented in Table 2.

Predictors for benzene concentrations were regular smoking in the home, a garage on the property, model-making activity in the previous three months, having opened the windows in the previous week to get fresh air into the home (reduced levels), and use of candles in the previous week.

The predictors for ethylbenzene, *m-, p*-xylenes and *o*-xylene were similar: a garage on the property, the number of occupants, renovations in the previous month, use of fragrance in the last 24 hours, and use of a paint remover in the previous week. As well, *m-, p*-xylenes had the additional predictor of regular smoking in the home.

Table 2
Contribution of predictors to log-transformed indoor BTEX concentrations, household population aged 3 to 79, Canada, 2009 to 2011

BTEX component	Predictors	% change	95% confidence interval from	to	*p*-value
Benzene (R^2 = 0.11)	Overall model	...	...	...	0.002
	Smoking in home every day/almost every day	136	95	189	<0.0001
	Presence of garage	60	36	90	<0.0001
	Model-making in past 3 months	31	1	72	0.0435
	Open windows on typical day in past week	-21	-36	-3	0.0279
	Use of candles in past week	12	-1	27	0.0781
Toluene (R^2 = 0.08)	Overall model	...	...	...	<0.0001
	Presence of garage	54	22	92	0.0012
	Use of paint in past week	52	9	112	0.0162
	Age of home (years)				0.0229
	Less than 20	46	15	86	0.0042
	20 to 39	32	-2	79	0.0621
	Use of paint remover in past week	82	7	206	0.0304
	Smoking in home every day/almost every day	31	6	60	0.0137
Ethylbenzene (R^2 = 0.05)	Overall model	...	...	...	0.0001
	Presence of garage	54	30	84	0.0001
	Number of occupants	24	38	5	0.0208
	Renovations in past month	39	4	86	0.0293
	Use of fragrance in past 24 hours	22	1	48	0.0415
	Use of paint remover in past week	82	7	213	0.0288
m-, p-Xylenes (R^2 = 0.05)	Overall model	...	...	...	<0.0001
	Presence of garage	58	31	90	0.0002
	Number of occupants	21	36	3	0.0278
	Renovations in past month	43	7	92	0.0203
	Use of fragrance in past 24 hours	22	0	48	0.0474
	Use of paint remover in past week	86	8	222	0.0272
	Smoking in home every day/almost every day	20	-3	49	0.0904
o-Xylene (R^2 = 0.06)	Overall model	...	...	...	<0.0001
	Presence of garage	68	40	103	<0.0001
	Number of occupants	21	36	1	0.043
	Renovations in past month	35	6	73	0.0203
	Use of fragrance in past 24 hours	22	1	49	0.0384
	Use of paint remover in past week	88	13	213	0.0193

... not applicable
Source: 2009 to 2011 Canadian Health Measures Survey.

Table 3
Indoor residential BTEX concentrations (µg/m³), by dwelling type, household population aged 3 to 79, Canada, 2009 to 2011

	Dwelling type						*p* - value		
	Single detached		Double, row/terrace, duplex		Low-rise or high-rise apartment		Single versus double/row/ duplex	Single versus apartment	Double/Row/ Duplex versus apartment
BTEX component	Mean	SE	Mean	SE	Mean	SE			
Benzene	1.47	0.19	1.76	0.19	2.13	0.20	0.3468	0.1037	0.4444
Toluene	8.68	1.22	13.16	1.70	23.70	2.92	0.1645	0.0000	0.0013
Ethylbenzene	2.56	0.84	4.20	1.00	4.43	0.50	0.1405	0.0000	0.0013
m-, p-Xylenes	8.11	2.25	12.02	2.32	16.72	1.94	0.1288	0.0000	0.0010
o-Xylene	2.47	0.81	3.81	0.80	4.74	0.55	0.0944	0.0000	0.0011

SE=standard error
Source: 2009 to 2011 Canadian Health Measures Survey.

The toluene predictors were a garage on the property, newer home, painting or use of paint remover in the previous week, and regular smoking in the home.

Apartments, garages

Type of dwelling was a significant predictor for all BTEX components in the univariate analyses, but not in any of the final models. Because of the questionnaire design, only respondents living in single-detached, double, duplex and row houses were asked about the presence of a garage on the property. Thus, the predictors "type of dwelling" and "presence of a garage" were related, and the final models included "presence of a garage," but not "type of dwelling." Further analyses were performed to examine differences in concentration between types of dwellings (Table 3). Levels of exposure were higher for toluene, ethylbenzene, *m-, p*–xylenes, and *o*–xylene in apartments than in single-detached, double, duplex and row houses.

Additional analyses were conducted for single-detached, double, duplex and row houses to determine the influence of the presence of a garage on BTEX concentrations (Table 4). Mean BTEX levels in homes with an attached garage (regardless of a connecting door) were approximately double those in homes without an attached garage. As well, benzene and toluene concentrations were significantly higher (p-value = 0.065 and 0.047) in homes with a connecting door to the garage versus homes without a connecting door; mean benzene concentrations were 3.09 and 2.13 µg/m^3, respectively, and mean toluene concentrations were 34.72 and 23.0 µg/m^3, respectively.

Discussion

According to the 2009 to 2011 CHMS, BTEX components are detectable in the indoor air in virtually all Canadian homes. The data in this study are nationally representative, and confirm recent findings that Canadians are exposed, in general, to relatively low levels of BTEX concentrations indoors. Moreover, a comparison with the results of a 1991 population-based study[21] of Canadian residences suggests a decline in exposure to BTEX components over time. This might reflect a reduction in VOC content in products, as well as reductions in ambient benzene concentrations. Mean benzene concentrations in the 1991 study ranged from 2.72 µg/m^3 (summer) to 6.98 µg/m^3 (fall), with a similar seasonal trend for ethylbenzene and the xylenes; toluene concentrations were lowest in winter and highest in spring, with values ranging from 17.88 to 84.34 µg/m^3. In the CHMS, means were 1.95 µg/m^3 for benzene and 19.17 µg/m^3 for toluene. The CHMS sample design yielded insufficient data to assess the influence of seasonal factors such as temperature and ventilation, which are important predictors of indoor BTEX levels.[22]

The BTEX concentration levels based on CHMS data differ somewhat from levels reported in studies conducted in Halifax,[23] Regina,[24] Windsor,[25,26] and Ottawa.[2] These differences may be attributable to the scope of the studies (nationally representative versus single city), sample sizes, the period of data collection, and the type of air sampler used.

Few published data are available on associations between indoor BTEX components. Héroux et al.[27] found strong correlations between ethylbenzene and the xylenes (r = 0.97–0.99). CHMS results are similar, but the associations are weaker. The lack of strong associations between benzene and toluene and with the other BTEX components could indicate different indoor sources. As well, the contribution of outdoor sources has been shown to be important, especially for benzene.[2,28]

In fact, although the predictors of BTEX concentrations in the CHMS data are generally consistent with those reported in other studies, the literature cites many other sources as being associated with indoor BTEX levels. For instance, the Total Exposure Assessment Methodology (TEAM) study identified two sources of benzene: a smoker in the home, but also, a gardener in the home. Some of the sources of ethylbenzene, *m-, p*-xylenes, and *o*-xylene identified as significant by the TEAM models were similar to those in the present analysis: age of the home; and smoker in the home. Other sources not included in the CHMS were: if an occupant had pumped gas that day; if an occupant worked with chemicals; and if the house was considered dusty. No TEAM data were available for toluene.[29]

Table 4
BTEX concentrations (µg/m^3), by garage configuration, household population aged 3 to 79, Canada, 2009 to 2011

	Garage configuration						*p* - value		
	Detached		Attached, no connecting door		Attached with connecting door		Detached versus no connecting door	Detached versus connecting door	No connecting versus connecting door*
BTEX component	Mean	SE	Mean	SE	Mean	SE			
Benzene	1.16	0.14	2.13	0.32	3.09	0.29	0.0153	0.0000	0.0654
Toluene	11.50	1.18	23.00	2.98	34.72	5.38	0.0006	0.0000	0.0473
Ethylbenzene	3.84	0.93	5.06	1.06	5.77	0.76	0.0155	0.0000	0.1578
m-, p- Xylenes	11.10	1.81	19.07	4.62	21.62	2.92	0.0233	0.0001	0.1849
o- Xylene	3.46	0.68	4.68	0.60	6.71	0.94	0.0075	0.0000	0.1200

SE=standard error
*attached garage only
Source: 2009 to 2011 Canadian Health Measures Survey.

What is already known on this subject?

- Benzene, toluene, ethylbenzene, *m-, p*-xylenes and *o*-xylene (BTEX) are ubiquitous in residential settings.
- Some indoor BTEX sources have been identified in the literature, but representative data for homes in Canada are limited.
- Chronic exposure to low BTEX concentrations may have health consequences.

What does this study add?

- According to the 2009 to 2011 Canadian Health Measures Survey, the indoor air in Canadian homes has relatively low BTEX concentrations.
- A comparison with the results of a 1991 population-based study of Canadian residences suggests a decline in exposure to indoor BTEX components over time.
- Significant predictors of BTEX included a garage on the property, regular smoking in the home, renovations in the past month, number of occupants, use of paint remover, and use of fragrance.

Using factor analyses of the VOCs measured in their study, Fellin and Otson[21] determined that ethylbenzene and the xylenes were associated with paint, outdoor air concentrations, and vehicle emissions. These differed from the predictors for ethylbenzene and the xylenes based on the CHMS data.

A study of residential indoor air in Regina[28] identified a number of benzene predictors including an attached garage, cigarette smoke, outdoor benzene levels, and use of hairspray. The toluene predictors included age of the home, attached garage, new furniture or rugs, and use of an air conditioner.

The EXPOLIS European study found the number of cigarettes smoked indoors to be a consistent predictor of benzene levels, with an increase of 16% to 17% per cigarette.[30]

According to the CHMS data, levels of exposure were higher for toluene, ethylbenzene, *m-, p*-xylenes, and *o*-xylene in apartments than in other housing types. Comparable Canadian data on BTEX concentrations by dwelling type are limited, although a Canada Mortgage and Housing Corporation report concluded that indoor air pollutant concentrations in the apartments studied were higher than levels in commercial buildings, and in single-family dwellings that used similar ventilation technology.[31] To some extent, the elevated BTEX concentrations in apartment buildings may be because they tend to be in more urban areas where ambient levels are higher.

In the present analysis, levels for all BTEX components were higher in homes with an attached garage. In particular, benzene and toluene levels were significantly higher in homes with a connecting door to the garage. Similarly, a Windsor study found benzene levels to be around three times higher in homes with an attached garage than in homes with a detached garage or no garage.[26] As well, the Boston Exposure Assessment in Microenvironments (BEAM) study reported that residences with an attached garage had significantly higher indoor BTEX levels than did homes without an attached garage.[32] In a 2006 article, Batterman et al.[33] estimated that about 16% of garage air infiltrated into the home.

Strengths and limitations

A strength of this study is the data source—a large, population-based survey which provides unique data that can be used in the risk assessment and risk management of BTEX components. For example, painting within the last week was identified as a predictor of toluene concentrations. This is not usually possible in surveys of air quality because of the small number of homes typically monitored and the improbability that home improvement projects would coincide with the sampling timeframe.

The limited number of questions in the CHMS restricted interpretation of the data, as evidenced by the low model r^2 values. However, because the r^2 value is an indicator of how well the predicted line fits the data, and is a poor indicator of the amount of variance explained for dichotomous predictors, the low r^2 values may also reflect the dichotomous nature of the predictors.

Exposure levels may be misclassified if an air sample is taken on only one day and in only one season. Thus, a further strength of this study is that the 7-day average sample was representative of weekly exposure—weekdays and weekends. At the same time, the 7-day average is a limitation because the BTEX concentration data cannot be analyzed by weekday/weekend when activities often differ. Averages also restrict the ability to relate peak exposures to specific activities.

Conclusion

Based on data from the only other population-based study of BTEX components, which was conducted in 1991,[21] it appears that the current CHMS levels of BTEX indicate a reduction in Canadians' exposure from indoor air concentrations. The sources of each of the components identified in this analysis are consistent with the literature. Predictors of BTEX concentrations included a garage on the property, regular smoking in the home, recent renovations, number of occupants, paint remover use, and fragrance use. Such information is a prerequisite for developing means of mitigating indoor BTEX sources. This is particularly important in the case of benzene, a non-threshold carcinogen, which is assumed to have health effects at all levels of exposure. Future data collection might be expanded to capture the influence of other sources such as traffic emissions and outdoor levels on indoor BTEX concentrations. ■

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