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Indoor and outdoor BTX levels in Barcelona City metropolitan area and Catalan rural areas

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Abstract

Five aromatic hydrocarbons (benzene, toluene, and three isomeric xylenes) were monitored in indoor and outdoor air of 7 public buildings and 54 private homes, located in Barcelona City metropolitan area and in several rural areas of Catalonia. The sampling was carried out over four periods: spring-summer and winter of 2000, and summer and winter of 2001. Passive ORSA 5 Dräger samplers were used for benzene, toluene, and xylenes (BTX) adsorption. BTX were extracted with carbon disulphide and analysed using a gas chromatograph coupled to a FID detector. In Barcelona metropolitan area the outdoor average concentrations of BTX were 3.5, 34.2, and 31.3 μg/m^3 in urban areas, and 1.4, 9.2, and 9.2 μg/m^3 in rural areas, respectively. Average indoor air concentrations of BTX were respectively 4.3, 64.8, and 47.6 μg/m^3 in urban areas and 5.8, 67.0, and 51.4 μg/m^3 in rural areas, respectively. A direct connection between the house and garage was one of the most influential factors for indoor BTX concentrations in rural areas. In urban areas, diffuse traffic sources were the predominant BTX source, slightly influenced by tobacco smoke in indoor air.

Key words: benzene, toluene, and xylenes (BTX); indoor air; outdoor air

Introduction

Aromatic hydrocarbons such as benzene, toluene, and isomeric xylenes are abundant in outdoor and indoor environments (Ilgen *et al*., 2001a, 2001b). Industrialization and the use of automobiles have led to an increased input of these organic chemicals to the atmosphere. Because of its worldwide distribution and ubiquity, and its carcinogenic properties, benzene is widely studied (WHO, 1993; Duarte-Davidson *et al*., 2001). Benzene is stable in the atmosphere and has low reactivity, and a relatively long lifespan in comparison with toluene and xylenes (Calvert *et al*., 2000; Hsieh and Tsai, 2003). Humans are exposed to benzene mainly through breathing polluted air (IEH, 1999). Therefore, great efforts have been devoted to identifying the sources of benzene in both indoor and outdoor air (Wallace, 1990, 1996; Duarte-Davidson *et al*., 2001). Benzene is emitted by vegetation and petroleum reservoirs (CONCAWE, 1994, 1997). However, because it is present in crude oil, natural gas, and unleaded gasoline, anthropogenic sources are the main contributors. Emissions from vehicle exhaust, evaporative loss, and incomplete fuel combustion processes are considered the main sources of benzene in outdoor air. Other variables to consider are the type and age of vehicles, the flow and speed of traffic, and the meteorological characteristics of the city (Muezzinoglu *et al*., 2001; Pilidis *et al*., 2005; Genikhovich *et al*., 2005; Khoder, 2007), which may vary with seasons. In winter, higher outdoor benzene levels are mainly owing to the contribution of heating systems, whereas in summer, benzene levels are lower because of photochemical degradation (Brocco *et al*., 1997; Cheng *et al*., 1997; Ilgen *et al*., 2001b; Na and Kim, 2001; Schneider *et al*., 2001). In private households, higher benzene concentrations have been detected in winter than in summer, mainly owing to the increased ventilation during summer seasons (Begerow *et al*., 1995).

Indoor benzene levels are usually higher than outdoor levels, indicating that several indoor sources may exist. Smoking has been identified as a major indoor source of benzene and contributes on average 2–3 μg/m^3 to the total indoor air concentration (Wallace, 1989; Ilgen *et al*., 2001a). Other sources identified, include cooking, heating, combustion products, cleaning products, solvent evaporation, construction work in the building (Schneider *et al*., 2001), laser printing, floor adhesives, paints and wood panelling (Etkins, 1996).

Garages contain cars, gasoline tanks and other small gasoline engines (Isbell *et al*., 1999; Edwards and Jantunen, 2001; Ilgen *et al*., 2001b). Several researchers have analysed the influence of a garage directly connected to living quarters on indoor benzene concentrations (Crump, 1997; Emmerich *et al*., 2003; Batterman *et al*., 2006).

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Toluene and xylenes are more abundant in gasoline than benzene and are also widely used in solvents. Therefore, outdoor and indoor levels of these compounds were expected to be higher than that of benzene. Despite the fact that their toxicity is lower than that of benzene, they have the same environmental fate and, when exposed to photochemical reactions in the atmosphere, produce compounds which can provoke adverse effects on human health. Therefore, the analysis of benzene, toluene, and xylenes (BTX) concentrations in indoor and outdoor air is necessary (Ilgen, 2001a; Palgrem *et al*., 2001; Schneider *et al*., 2001; Muezzinoglu, 2001; Kim and Kim, 2002; Pilidis *et al*., 2005; Khoder, 2007).

Public concern over benzene hazards has increased over the years, and is currently focused on the effects of continuous exposure to low concentrations of this compound, both occupationally and non-occupationally (Duarte-Davidson *et al*., 2001). Several measures have been adopted to reduce BTX emissions to the atmosphere. For example, the EU restricted benzene concentrations in consumer products to $\leqslant$ 0.1%, except for gasoline, the limit of which was set at 1% (89/677/ECC, European Directive). Gasoline transference and storing processes were also regulated (94/63/CE, European Directive). The EU set a recommended limit of 10 $\mu g/m^3$ of benzene for air concentrations, effective until January 2006 (2000/69/CE, European Directive); thereafter, this should be decreased by one unit per year until January 2010.

In the present study, BTX concentrations were determined for several corresponding indoor and outdoor environments in urban and rural areas, over four sampling periods. The majority of samples were taken in the metropolitan area of Barcelona, while one fifth came from rural areas located around Catalonia.

1 Experimental sections

1.1 Sampling areas

The samples were collected in selected homes and public buildings in the metropolitan area of Barcelona (around 3 million inhabitants), and in homes of several small villages in Catalonia (fewer than 400 inhabitants). There were 48 and 13 sampling points for indoor/outdoor environments in urban and rural areas, respectively. Many urban sampling points were selected as traffic density locations, which were in buildings from 4 to 8 floors, usually used as private dwellings, except the public buildings. Rural settlements were generally located in low traffic density areas, typically family private homes with surrounding gardens or patios.

The Barcelona metropolitan area is characterized by a Mediterranean climate. Winters are mild, with average temperatures of 7–10°C. Summers are cool, with average temperatures of 20–26°C, high pressure and varying humidity levels, making rainfall unlikely except for the odd thunderstorm. In contrast, the studied areas in Catalonia rural have a continental Mediterranean climate, with clear differences between summer and winter. Winters are cold, with average temperatures of 1–6°C, whereas summers are cool, with average temperatures of 22–26°C and low levels of humidity.

1.2 Overview of the sampling strategies and protocol

The inhabitants of the sampling areas were invited through the mail to participate in the study. Sampling was carried out during April, 2000 to January, 2002, in four sampling periods: spring-summer 2000 (April–June 2000), winter 2000 (December 2000–February 2001), summer 2001 (June–September 2001), and winter 2001 (November 2001–January 2002). Indoor and outdoor air was monitored using passive sampling over 21 d to enhance sensitivity.

For every sampling point, a questionnaire was filled out with relevant information about potential BTX sources, which was fundamental for further interpretation of the data. For outdoor environments, the questionnaire included information about traffic density and the proximity of direct BTX sources, i.e., gas stations. For indoor environments, factors included the type of room, tobacco smoke occurrence, and the connection between the garage and the living quarters of the house.

The meteorological data used in the present study was supplied by the Meteorological Service of the Government of Catalonia.

1.3 Sampling

Passive ORSA 5 Dräger (Lübeck, Germany) samplers were used for BTX adsorption, which were protected against negative weather conditions whenever necessary. In standard sampling, limiting operational conditions were not exceeded (temperature 0–40°C; relative humidity 5%–80%). Each sample was labelled and the initial and final sampling times were registered. As soon as the sampling process was over, tubes were replaced in the protector container and sent to the laboratory for analysis. Tubes were stored in the dark at 4°C. The aromatic hydrocarbons were eluted with 2 ml of carbon disulphide for 45 min. All concentration calculations were performed using the equivalent flow constant provided by Dräger.

1.4 Instrumental methods and materials

1.4.1 Chemicals and standards

Benzene, toluene, *m*-xylene, *o*-xylene, *p*-xylene, and *n*-propylbenzene were obtained from Merck (Darmstadt, Germany) (all of the purity > 99%), carbon disulphide was provided by Fluka (United Kingdom, purity $\geqslant$ 99.5%). Standard solutions of the above aromatic hydrocarbons were made up using a freshly prepared and homogenized solution of 50 µl (via a pre-weighed 100 µl Hamilton syringe) of each standard and put into a clean 10 ml flask, resulting in an individual compound concentration of about 5,000 ng/ml. From this solution other standards were prepared by mixing and diluting when required. All the standard solutions were prepared on the day of use, and stored at 4°C in darkness.

n-Propylbenzene was used as an internal standard for GC analyses. An extraction efficiency of 98%–100% was

obtained for all analytes, since extraction was carried out at low temperature to prevent evaporative analyte losses. The detection limits were below 0.5 g/m^3 for all analytes. Extreme precautions are required for ensuring reproducible and quality, and the blanks were added to every set of samples.

1.4.2 Analytical instruments

The samples obtained through carbon disulphide elution were analysed by gas chromatography (GC) with a flame ionisation detector (FID) (Hewlett-Packard, 6890 model series, Palo Alto, USA). A column from J&W Scientific (Folsom, USA), type DB-WAX, 60 m in length, 0.25 mm i.d., 0.25 μm film thickness was used with the following temperature programme: 8 min at 60°C and 60–120°C in 2°C/min. The sample 2 μl was injected in the split mode (60:100) into a split/splitless injector. Injector and detector temperatures were 200 and 250°C, respectively. Helium was the carrier gas, H_2 and synthetic air were the combustion gases.

2 Results and discussion

2.1 Outdoor air

The results for outdoor concentrations of benzene, toluene and the sum of xylenes for both rural and urban areas are summarized in Table 1. Average concentrations of each compound in the outdoor air of the urban areas significantly exceed those in the rural areas ($p < 0.0001$). The average concentration observed for benzene in the metropolitan area of Barcelona is similar to that observed in other European cities, such as Birmingham (3.3 μg/m^3), Cardiff (3.9 μg/m^3), Edinburgh (2.3 μg/m^3), Bristol (4.0 μg/m^3), London (3.5 μg/m^3), Liverpool (2.9 μg/m^3, Copenhagen (2.9 μg/m^3), and Toulouse (1.1–2.0 μg/m^3) (Derwent *et al*., 2000; Skov *et al*., 2001; Simon *et al*., 2004), but lower than that in several African and Asian cities (Ramsis (87.2 μg/m^3), Haram (46.2 μg/m^3), Hong Kong (10.1–15.1 μg/m^3), and Suzhou (7.2–13.3 μg/m^3)) (Lee *et al*., 2002; Costabile *et al*., 2006; Khoder, 2007). However, average concentrations of toluene and xylenes are higher than that generally observed in European cities, excluding Ioannina (Greece), Rome (Italy) and Izmir (Turkey) (Brocco *et al*., 1997; Muezzinoglu *et al*., 2001; Pilidis *et al*., 2005). Similar to benzene, the toluene and xylene concentrations in several African and Asian cities are higher than those observed in Barcelona.

Average benzene concentrations in rural areas of Catalonia are similar to those in Wedemark (Germany) (1.3 μg/m^3) and Coles Farm (0.8 μg/m^3), Rowan College (1.2 μg/m^3), Turnesville (1.5 μg/m^3) and Western Springs (0.6 μg/m^3) (USA) (Ilgen *et al*., 2001a; Pankow *et al*., 2003). However, average concentrations of toluene and xylenes in the same areas are higher than those observed in the above mentioned rural areas of Germany and the USA.

Figure 1 represents the annual course of outdoor and indoor BTX concentrations for both urban and rural areas. In rural areas, the first sampling period lasted from April 2000 until May 2000; samples were not taken during the summer season in 2000. Furthermore, severe weather conditions in the selected rural areas in winter of 2000/2001 meant that sampling could not take place.

In both urban and rural areas a reduction in BTX concentrations is observed in the summer seasons; however, in the winter seasons the differences are not so pronounced. This may be explained by a reduction in heating in homes and an enhanced photochemical degradation during the summer (Ilgen *et al*., 2001a; Schneider *et al*., 2001; Lee *et al*., 2002; Pilidis *et al*., 2005), when a removal of BTX is caused by OH radicals (Brocco *et al*., 1997). The annual variation of the outdoor level of benzene is better reflected if the concentration is plotted as a function of temperature, observing a significant negative correlation between benzene concentrations and temperature in rural areas ($r^2 = 0.668$, $p < 0.05$) (Fig.2), as observed in previous studies (Ilgen *et al*., 2001a). A positive correlation is also observed between benzene concentrations and relative humidity ($r^2 = 0.638$, $p < 0.05$) in rural areas (Fig.2), and temperature and relative humidity are negatively well correlated in these areas ($r^2 = 0.867$, $p < 0.01$) (Fig.2). However, these correlations are not observed in urban areas, probably due to other factors such as traffic density, which dominates outdoor benzene concentrations.

On 13 November, 1999, Royal Decree 1728/1999 was published by the Spanish government, reducing benzene concentrations in leaded and unleaded gasoline from 5% to a maximum of 1%. The legal application was 1 January 2000. Considering that it may be several months before the Decree affects concentrations of benzene and other hydrocarbons in the atmosphere, the differences between the spring season of 2000 and the rest of the sampling periods observed in this study may be a result of the Decree.

If we compare the individual outdoor data obtained both in urban and rural areas for high and low traffic density

Table 1 Outdoor air concentrations of BTX in rural and urban areas (unit: μg/m^3)

	Benzene		Toluene		Sum of xylenes	
	Rural areas	Urban areas	Rural areas	Urban areas	Rural areas	Urban areas
Arithmetic mean	1.4	3.5**	9.2	34.2**	9.2	31.3**
Standard deviation	1.5	1.9	15.2	20.0	14.1	17.1
Minimum	0.2	0.5	0.5	4.3	0.5	0.5
Maximum	8.3	12.4	95.4	121.3	56.6	91.9
The 5th percentile	0.3	0.8	1.1	14.8	0.5	8.3
The 50th percentile	1.0	3.2	4.6	30.3	2.5	28.5
The 95th percentile	3.2	6.5	29.4	63.6	40.4	63.8

Number of samples in rural areas: 47; number of samples in urban areas: 164. ** $p < 0.0001$.

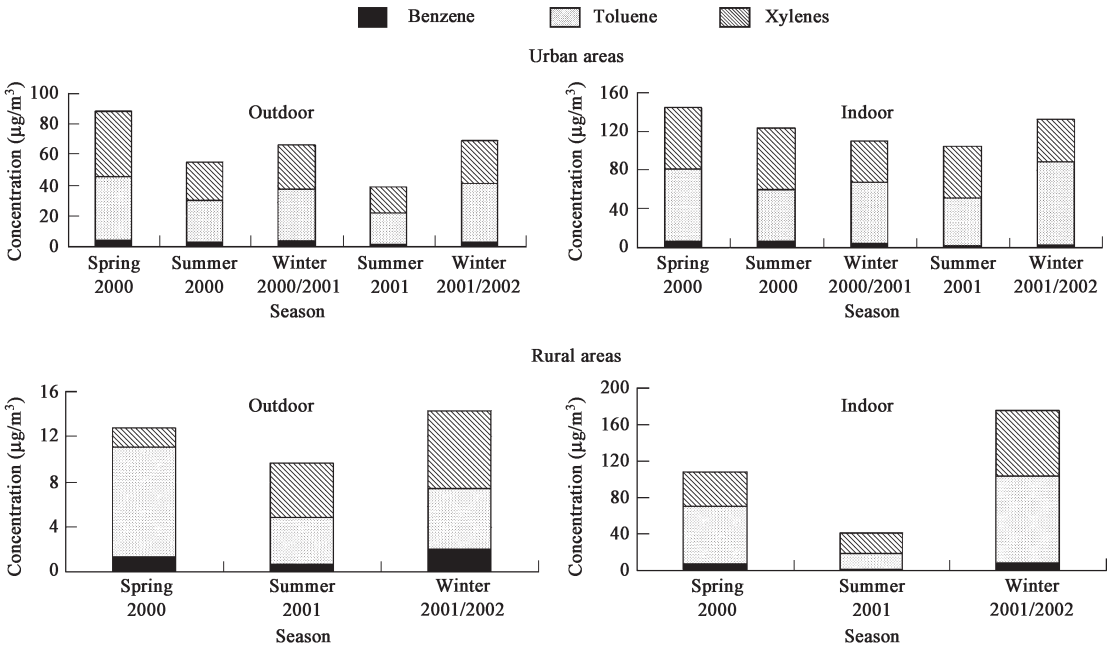

Fig. 1 Seasonal variation in the concentration of benzene, toluene and the sum of xylenes in outdoor and indoor air of urban and rural areas.

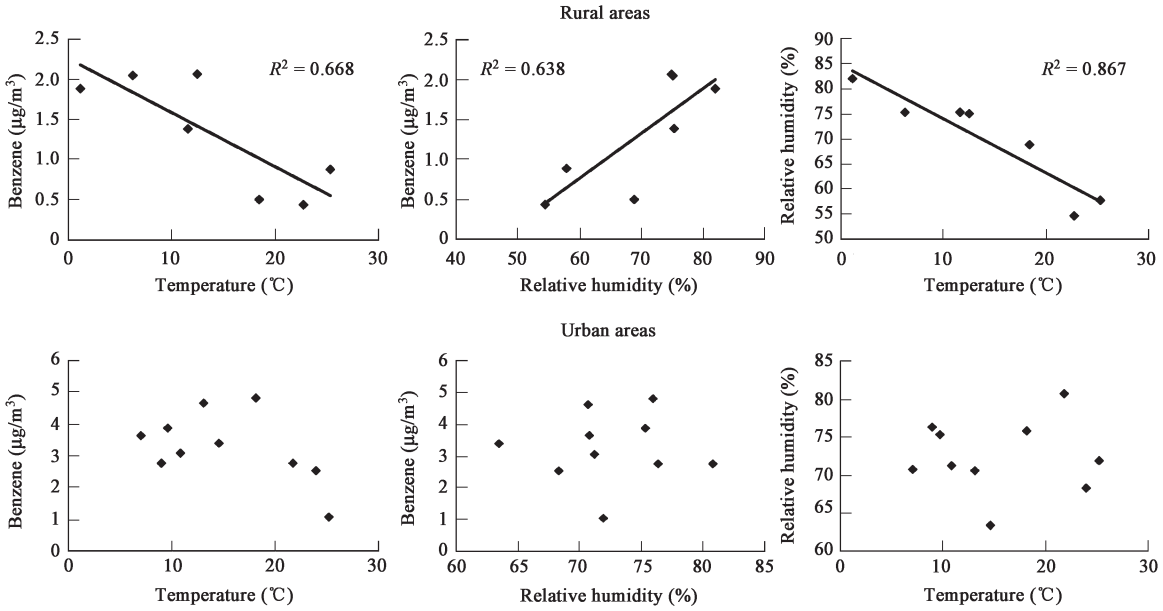

Fig. 2 Mean monthly benzene concentration in outdoor air as a function of the outdoor temperature and relative humidity, and mean monthly relative humidity as a function of the outdoor temperature in rural and urban areas.

streets, benzene concentrations are significantly higher ($p < 0.0001$) in cases of high traffic density. Considering that benzene use is now highly reduced and controlled, these results probably only reflect the contribution of traffic to the atmosphere. In contrast, the concentrations of toluene and the sum of xylenes seen in urban and rural areas do not show significant differences between high and low traffic density streets. As toluene and xylenes are largely used as solvents, their existense must come from sources other than traffic. In addition, photochemical degradation of toluene and xylenes is faster than that of benzene (Ilgen *et al.*, 2001a), meaning that it is easier to see the relationship between benzene and traffic density.

2.2 Indoor air

The results for indoor concentrations of benzene, toluene, and the sum of xylenes for both rural and urban areas are summarized in Table 2. The average concentrations of benzene and xylenes in the indoor air of the rural areas significantly exceed ($p < 0.001$ and $p < 0.05$, respectively) those in urban areas; however, in summer indoor rural values are lower than those observed in urban areas (Fig.1).

In Fig.1, the variations of indoor BTX concentrations are shown for urban and rural areas. In urban areas,

Table 2 Indoor air concentrations of BTX (μg/m^3) in rural and urban areas

	Benzene		Toluene		Sum of xylenes	
	Rural areas	Urban areas	Rural areas	Urban areas	Rural areas	Urban areas
Arithmetic mean	5.8	4.3**	67.0	64.8	51.4	47.6*
Standard deviation	7.8	3.7	108.6	64.4	73.0	36.2
Minimum	0.2	0.5	2.0	1.1	0.5	0.5
Maximum	70.6	36.0	559.3	644.5	310.6	307.9
The 5th percentile	0.5	1.1	2.8	22.6	0.5	16.1
The 50th percentile	2.2	3.6	14.6	48.8	15.9	36.8
The 95th percentile	19.5	8.5	205.6	138.4	187.8	106.5

Number of samples in rural areas: 57; number of samples in urban areas: 183. * $p < 0.05$; ** $p < 0.001$.

significant differences ($p < 0.05$) are observed for benzene and xylenes between spring of 2000 and the rest of the seasons. However, significant differences are not observed in urban environments between summer and winter seasons, whereas in rural areas significant differences are detected for BTX ($p < 0.05$ for each compound).

As observed in previous studies, BTX concentrations in private homes are generally lower in summer seasons than in winter seasons (Sung-Ok *et al*., 1997; Ilgen *et al*., 2001b), mainly owing to higher ventilation rates during summer (Begerow *et al*., 1995, Crump, 1997; Schneider *et al*., 2001). In the present study, only rural areas corroborate this observation, probably owing to the cleanliness of the rural outdoor air in summer compared to urban outdoor air (Fig.1), leading to a higher factor of dilution of indoor air concentrations in rural than in urban areas. The contribution of wood central heating to indoor BTX concentrations (Ilgen *et al*., 2001b) has also been studied. However, statistical differences have not been observed between places whether timber is used to heat homes.

2.2.1 Smoking habits

Statistically significant differences are observed for benzene concentrations between smoking and non-smoking apartments in urban areas, with higher concentrations of benzene detected in the former ($p < 0.05$, Table 3). In rural areas, however, no differences were detected, which may be explained by the small number of smoking cases (only 2 cases out of 13) in the rural samples.

The reports show that smoking contributes significantly to the concentrations of benzene in indoor air (Thomas *et al*., 1993; Wallace, 1996; Crump, 1997; Leung and Harrison, 1998; Duarte-Davidson *et al*., 2001; Godish, 2001; Ilgen *et al*, 2001b), and previous studies also show that regular smoking over a sampling period leads to maximum concentrations of benzene in indoor air of up to 57 μg/m^3 (Duarte-Davidson *et al*., 2001).

2.2.2 Garages

Garages in urban areas are in the underground floors of buildings, generally quite well isolated from the flats, but in our rural sample areas the garages are separated from the indoors of buildings simply by a door, which usually connects the garage directly to the living quarters.

Significant differences are observed between BTX concentrations in rural area houses with a garage and houses without one ($p < 0.01$ for each compound), indoor air concentrations of BTX being higher in houses with a garage (Table 3). In contrast, no differences are detected in the indoor BTX concentrations in urban apartments with or without a garage (Table 3). In detached houses, the movement of BTX from the garage to other building spaces has been observed in several studies (Thomas *et al*., 1993; Duarte-Davidson *et al*., 2001; Ilgen *et al*. 2001a; Emmerich *et al*., 2003; Batterman *et al*., 2006), in some cases resulting in an 80% increase in indoor concentrations of BTX in the house (Crump, 1997). BTX garage emissions come not only from combustion in the car while it is being parked in or leaving the garage but also from other sources, such as stored products like solvents, paints, oils and cleaning products, and the evaporation of gasoline from machines such as lawnmowers (Ilgen *et al*., 2001a; Emmerich *et al*., 2003; Batterman *et al*., 2006). Even though the contribution of these products to total indoor BTX levels is considerable, the concentrations observed in garages are considered traffic-related, as cars, motorbikes and gasoline leakage are the main contributors of BTX to garage indoor air (Ilgen *et al*., 2001a), and consequently to household indoor air.

Higher BTX concentrations in rural indoor air than in urban environments may result from the combination of many factors, which include the presence of a garage connected to the house, reduced ventilation in the winter accentuating the garage effect, and furthermore, the combustion of wood for central heating.

Table 3 ANOVA *P*-values of the different variables studied in indoor air of urban and rural samples

	Urban areas			Rural areas		
	Smoking indoor	Vehicle garage	High traffic density	Smoking indoor	Vehicle garage	High traffic density
Benzene	0.019*	0.136	0.050*	0.398	0.010*	0.009*
Toluene	0.054	0.801	0.108	0.351	0.010*	0.010*
Sum of xylenes	0.358	0.809	0.128	0.246	0.010*	0.084

* Statistical evidence for the differences between the average values was attributed to *p*-values where $p \leqslant 0.05$.

2.2.3 Traffic density

Significant differences are observed in benzene indoor concentrations in urban areas between apartments located in high and low traffic density areas ($p < 0.05$), with higher concentrations found in high traffic areas (Table 3). The same is observed in rural homes for benzene and toluene ($p < 0.01$ for each compound) (Table 3). As discussed above, higher concentrations of benzene in the outdoor air are owing to a high traffic density both in urban and rural areas. This outdoor air infiltrates buildings and enters households, influencing indoor air concentrations, especially in winter months because of low ventilation rates (Crump, 1997; Duarte-Davidson *et al*., 2001).

3 Indoor/outdoor relationship

The ratio of indoor concentration (I) to outdoor concentration (O) (I/O) of each of the compounds studied reflects the importance of outdoor sources versus indoor sources. If $I/O > 1$, indoor sources contribute considerably to BTX concentration. Because outdoor values used in the present study come from sampling points located outside the windows of the dwellings chosen for the study, the I/O data obtained are reliable. I/O values are summarized in Table 4, which shows I/O values for rural areas are approximately 3 times higher than I/O values for urban areas ($p < 0.0001$), indicating a strong presence of indoor sources of BTX in rural areas. However, in urban areas the I/O ratio for benzene is close to 1; in this case, outdoor benzene concentrations are responsible for the concentrations of this compound indoors, whereas in urban areas the sources of toluene and xylenes are more likely to be indoors, probably owing to their use as solvents in building materials (Skov *et al*., 2001).

Both in urban and rural areas, outdoor air concentrations of benzene and toluene, toluene and xylenes, and benzene and xylenes are highly correlated (t-test on 99% confidence interval), with r^2 between 0.5345 and 0.6288 (Table 5). This observation corroborates the hypothesis that the BTX compounds studied are emitted directly from traffic (Monod *et al*., 2001; Muezzinoglu *et al*., 2001; Skov *et al*., 2001; Lee *et al*., 2002; Costabile *et al*., 2006; Khoder, 2007). In addition, indoor air concentrations of the various BTX compounds are correlated in urban and rural areas (t-test on 95%–99% confidence interval). The correlations are higher in rural areas, with r^2 from 0.854 to 0.960 (Table 5). This suggests that the BTX levels found indoors in rural areas are also traffic related, with the strong indoor sources mentioned above coming from the garage, as the distributions of BTX found are typically from traffic, with a BTX ratio of 1:3.5:4.2 (Lee *et al*., 2002; Vardoulakis *et al*., 2005; Khoder, 2007).

Table 4 Indoor/Outdoor mean ratios (±SD) in urban and rural areas

Component	Indoor/Outdoor ratio		p-value[a]
	Mean urban areas (±SD)	Mean rural areas (±SD)	
Benzene	1.48 ± 1.68	5.95 ± 9.91	0.0001
Toluene	2.29 ± 3.01	9.26 ± 14.98	0.0001
Sum of xylenes	3.19 ± 9.40	9.38 ± 13.16	0.0001

[a] Statistical evidence for differences between the distributions and median values was attributed to p-values where $p < 0.05$.

Table 5 t-Test r^2 values for linear regressions between the BTX studied

	Urban areas		Rural areas	
	Outdoor	Indoor	Outdoor	Indoor
Benzene vs. Toluene	0.5345**	0.3841**	0.585**	0.878**
Benzene vs. Xylenes	0.5592**	0.1979*	0.602**	0.854**
Toluene vs. Xylenes	0.6288**	0.3916**	0.561**	0.960**

* $p < 0.05$; ** $p < 0.01$.

4 Conclusions

Indoor and outdoor BTX concentrations were determined in the Barcelona metropolitan area and in several rural areas of Catalonia. Higher outdoor BTX concentrations were found in urban areas in comparison to rural areas. Outdoor concentrations of benzene were related to traffic density, with higher concentrations obtained in high traffic density streets. A reduced BTX concentration was observed in the summer season, probably as a result of photochemical degradation during summer and the use of residential heating systems during winter. The annual variation of benzene correlates significantly with temperature in rural areas, and a negative correlation is observed between benzene concentrations and temperature.

Higher indoor BTX concentrations were found in the rural areas compared to urban areas. Rural BTX concentrations were lower in the summer than in the winter seasons, probably owing to increased ventilation in the summer. A garage directly connected to the house was identified as one of the most influential factors in indoor BTX levels for rural environments. In urban environments, vehicle emissions were the predominant sources of BTX. However, an important factor is tobacco smoke, which increased benzene concentration in indoor air.

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