Building and Environment 78 (2014) 89–94

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Volatile organic compounds in aircraft cabin: Measurements and correlations between compounds

Chao Wang, Xudong Yang*, Jun Guan, Kai Gao, Zheng Li

Department of Building Science, Tsinghua University, Beijing 100084, PR China

ARTICLE INFO

Article history:
Received 21 October 2013
Received in revised form
21 April 2014
Accepted 22 April 2014
Available online 2 May 2014

Keywords:
Aircraft cabin
Measurement
Volatile organic compound
Correlation

ABSTRACT

Volatile organic compounds (VOCs) are an important class of air pollutants in aircraft cabin. The present study aimed to measure the VOC concentrations and determine possible correlations between selected VOCs in samples of 14 domestic flights in China. Alkanes and alkenes, aromatics, and aldehydes were the most abundant compounds on 9 flights, 4 flights, and 1 flight, respectively. Nineteen primary VOCs were quantified, and the mean concentrations of benzene, toluene, ethylbenzene, p-xylene (represent m,p-xylene), and o-xylene of all flights were 14.78, 29.84, 7.04, 4.83, and 4.55 μg/m^3, respectively. The contributions of VOC groups to the total VOC concentration differed on each flight. Correlations between the 19 VOCs were conducted and only a few pairs were found to be strongly correlated ($p \leq 0.001$). Strong correlations were obtained between ethylbenzene and *p*-xylene, *p*-xylene and *o*-xylene, decanal and nonanal, and dodecane and undecane for all flights. This work will provide the foundation for future studies to identify the primary sources of VOCs in aircraft cabin air.

1. Introduction

Many pollutants are present in aircraft cabin environment, of which volatile organic compounds (VOCs) are important because they may cause potential risk to the health and comfort of passengers and crew members. Most of the aromatic compounds are listed as toxic (e.g., benzene) or potentially toxic (e.g., toluene, xylenes) air contaminants at specific exposure levels [1]. In addition, considering the existence of ozone in an aircraft cabin [2], reactions between ozone and VOCs may lead to formation of additional airborne toxic chemicals and fine particles [3].

Because of the potential risks associated with VOCs, it is important to accurately determine the current status and characteristics of these compounds in aircraft cabin. The data would allow identification of emission sources and development of appropriate strategies to control VOC concentrations. Concentrations of VOCs in aircraft cabin have been investigated in a few previous studies [4–12]. However, reporting the concentration data alone is not sufficient to determine VOC characteristics in aircraft cabins and identify possible emission sources.

In general, emission sources such as interior air cabin materials are most commonly evaluated via laboratory studies. However, given that many potential sources may be present in aircraft cabin, it is not realistic to investigate every source in this way. Concentration data in actual aircraft cabin, if properly analyzed, may yield more information and help to determine the characteristics of emission sources.

Determining the mixing ratios and correlations between certain VOCs is an important method for investigating the characteristics of VOC mixtures and for identifying their primary sources. Similar methods have been widely used in the atmospheric field [13–19]. The basic principle of these methods is that a constant mixing ratio or a good correlation between VOCs among a group of samples strongly suggests that the pair of VOCs could have the same source or source array.

As examples in the atmospheric field, Nelson and Quigley [16,17] found that the ratio between ethylbenzene and *m*-/*p*-xylene was 3.6 in the Sydney area, comparable to the results of other studies. They also found the ethylbenzene to *m*-/*p*-xylene ratio was nearly constant for various sources, such as vehicle exhaust, solvent petrol, fuel evaporation, etc. According to the results, they concluded that these VOC pairs may come from sources mentioned above. Monod et al. [14] studied correlations between *m*-/*p*-/*o*-xylene and ethylbenzene in various cities. The consistent ratios obtained between *m*-/*p*-/*o*-xylene and ethylbenzene in all locations investigated indicated that these compounds may have the same sources globally. However, no particular sources were identified in their study. Derwent et al. [13] found good correlations between ethylene and

* Corresponding author. Tel.: +86 10 6278 8845; fax: +86 10 6277 3461.
E-mail address: xyang@mail.tsinghua.edu.cn (X. Yang).

http://dx.doi.org/10.1016/j.buildenv.2014.04.016
0360-1323/

Table 1
Flight information.

Flight	Date (yymmdd)	Aircraft	From	To	Duration (min)
1	20120917	B737-800	Tsingtao	Chengdu	170
2	20120917	B737-800	Chengdu	Tsingtao	150
3	20120918	B737-800	Tsingtao	Kunming	190
4	20120918	B737-800	Kunming	Tsingtao	170
5	20120919	B737-800	Tsingtao	Beijing	80
6	20120922	B737-800	Beijing	Tsingtao	80
7	20120923	B737-700	Tsingtao	Guangzhou	180
8	20120923	B737-700	Guangzhou	Tsingtao	165
9	20120924	B737-800	Tsingtao	Harbin	110
10	20120924	B737-800	Harbin	Tsingtao	120
11	20120925	B737-800	Tsingtao	Shanghai	80
12	20120925	B737-800	Shanghai	Tsingtao	85
13	20120926	B737-800	Tsingtao	Shenzhen	180
14	20120926	B737-800	Shenzhen	Tsingtao	165

benzene among 11 English cities, which was useful in identifying the probable source. The ethylene vs. benzene scatter plots showed evidence of VOC emission events due to non-motor vehicle sources. However, to date, similar investigations have not been conducted for the aircraft cabin environment.

The present study aimed to determine the concentration mixing ratios and correlations between selected VOCs in a large number of samples taken at various locations during 14 domestic flights in China. These results provide detailed information on VOCs in aircraft cabin, which will provide the foundation for future studies to identify the primary sources of VOCs in aircraft cabin air.

2. Materials and methods

2.1. Sampling sites and periods

VOC sampling was conducted on board of 14 flights in China (Table 1). The measurements took place from 17 to 26 September 2012. The flight duration ranged from 80 to 170 min. The northernmost city was Harbin (125°42′–130°10′ E, 44°04′–46°40′ N) and the southernmost city was Shenzhen (113°46′–114°37′ E, 22°27′–22°52′ N).

The aircraft type for all flights was Boeing 737, a single-aisle airplane that can seat 162–189 passengers [20]. The cabin was furnished with plastics on the cabin wall, fabric curtains, carpets on the floor, and the seats were made of textile with fire retardant coating. The cabin environment was centrally conditioned by the environmental control system (ECS). A personalized air supply gasper was equipped above each seat. The aircraft was also equipped with ozone scrubbers to remove ozone from outside air.

VOC sampling in cabin air was taken at a height of ~1.2 m above the floor, directly in front of the testing personnel's chest and in the breathing zone. Samples were collected during different stages of the flight (i.e., takeoff, climbing, cruising, descending, and landing).

2.2. Sampling and analysis

Cabin VOC samples were collected using Tenax TA tubes (Markes Intl. Ltd., Llantrisant, UK), following the standard method developed by the United States Environment Protection Agency [21]. Air was drawn through the Tenax TA tubes using a sampling pump (*Libra Plus*™ LP-1, A. P. BUCK INC., USA) calibrated to draw at 200 mL/min [22], for 5 min (total sample volume 1000 mL). After each sampling, the two ends of the Tenax TA tube were tightly sealed using special brass caps made by the Tenax TA tube supplier. After sampling, the tubes were delivered to the laboratory, and held at −10 °C in a freezer. All tubes were analyzed within 14 days after sampling.

For analysis, the Tenax TA tubes were placed in a thermal desorber (TD; Markes Intl. Ltd.). After desorbing, the carrier gas containing VOCs went into a gas chromatograph (GC) (Model 6875; Agilent Technologies, Inc., Santa Clara, CA, USA) fitted with a mass spectrometer (MS) (5975B; Agilent). The thermal desorption system was a two-stage unit which the tube desorption was held at a temperature of 250 °C for 10 min and the trap desorption at 300 °C for 3 min. An HP-VOC capillary column (30.0 m × 200 μm × 1.12 μm film thickness; Agilent) was used with He as a carrier gas at a flow rate of 3 mL/min. The initial temperature of the oven was 40 °C for 4 min, then was brought up to 250 °C at 10 °C/min and held for 5 min. The instrument was checked daily to confirm the retention times and responses of selected compounds in the standard calibration mixture.

2.3. Quality control and assurance

Quality control for the entire sampling process included laboratory and field blanks. Before each measurement, the sampling

Table 2
Mean VOC concentrations during 14 flights (in μg/m^3).

VOC	Flight 1	Flight 2	Flight 3	Flight 4	Flight 5	Flight 6	Flight 7	Flight 8	Flight 9	Flight 10	Flight 11	Flight 12	Flight 13	Flight 14	Mean
Benzene	23.03	56.95	21.28	17.86	13.74	9.31	9.08	6.64	8.97	7.54	8.61	6.81	4.49	12.60	14.78
Toluene	8.45	46.87	11.79	12.98	9.37	14.42	20.63	80.37	14.17	21.25	8.39	6.73	39.28	123.08	29.84
Ethylbenzene	4.20	9.58	4.06	5.55	3.90	8.81	10.56	4.43	5.30	7.55	1.47	2.09	8.59	22.55	7.04
p-Xylene	2.78	6.57	2.79	3.39	2.23	4.09	6.48	3.28	3.95	1.95	1.86	1.16	6.19	20.92	4.83
o-Xylene	2.79	6.80	3.05	3.73	3.31	2.74	6.17	3.51	4.66	3.19	2.66	1.25	5.44	14.42	4.55
Decanal	23.89	24.57	35.52	29.74	32.38	32.77	31.25	16.39	21.92	25.76	17.76	14.16	23.84	30.91	25.78
Nonanal	17.58	16.99	24.23	20.55	23.44	23.51	22.28	10.68	16.78	18.69	16.48	14.62	18.78	16.55	18.65
Dodecane	5.41	4.19	4.79	2.97	13.42	6.41	6.81	5.09	4.65	7.85	8.87	4.99	6.12	8.54	6.43
Undecane	2.00	1.66	2.05	1.71	5.82	3.11	3.56	1.75	0.87	4.18	4.30	4.41	3.44	2.35	2.94
Octanal	6.80	6.09	10.23	8.04	9.49	8.07	3.03	4.03	3.69	7.76	6.55	6.51	4.41	3.44	6.30
1-Hexanol, 2-ethyl-	4.79	4.90	4.81	5.13	6.92	10.50	7.78	7.67	8.49	11.59	11.90	7.67	4.84	11.56	7.75
Tetrachloroethylene	3.27	2.13	2.79	4.51	2.91	5.01	3.85	0.60	3.25	1.87	0.94	0.83	2.59	6.68	2.94
Benzaldehyde	6.12	4.14	4.60	4.20	4.37	6.21	5.24	7.20	1.08	0.15	13.88	7.62	6.38	8.38	5.68
d-Limonene	15.77	5.47	50.21	60.12	81.12	16.08	68.01	25.06	259.04	163.90	69.27	24.61	6.91	276.32	80.13
Acetic acid	11.76	11.16	7.55	11.61	8.76	15.44	15.53	9.24	9.67	14.63	4.04	9.54	8.60	6.51	10.29
5-Hepten-2-one, 6-methyl-	8.57	6.37	12.05	11.66	14.78	16.38	9.12	7.59	0.21	8.47	5.53	3.69	11.88	7.79	8.86
Styrene	2.50	3.49	2.85	0.84	0.64	2.33	1.05	2.25	3.11	0.70	1.82	0.54	0.56	6.13	2.06
Menthol	2.48	1.61	1.34	2.31	10.16	9.81	1.04	3.71	3.38	7.61	3.55	2.18	4.31	7.03	4.32
Acetone	4.03	9.80	3.21	2.66	5.42	0.46	1.97	2.29	6.53	6.89	6.00	0.46	3.38	6.66	4.27
Total	157.22	231.33	212.19	213.56	257.15	201.45	240.41	209.77	388.72	331.51	204.87	131.84	183.01	606.41	254.96