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Journal of Hazardous Materials A95 (2002) 1–12

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Characteristics of polycyclic aromatic hydrocarbons and total suspended particulate in indoor and outdoor atmosphere of a Taiwanese temple

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Received 8 June 2001; received in revised form 19 February 2002; accepted 14 May 2002

Abstract

Incense burning, a common and popular practice among many families and in most temples in Taiwan, can result in indoor pollution-related health problems. This exploratory study was aimed at characterizing human exposure to polycyclic aromatic hydrocarbons (PAHs) and total suspended particulate (TSP) inside and around a Taiwanese temple, and to compare the indoor levels with levels outside. Additionally, three types of commonly used unburned incense and incense ash were analyzed in order to evaluate the relationship between incense composition and PAH emissions.

Standard methods were used to determine air concentrations of 21 PAHs and TSP inside and around a chosen temple. Indoor mean total-PAH concentration, particle-bound PAH concentration and TSP concentration were 6258 ng/m^3, 490 μg/g and 1316 μg/m^3, respectively; values for outdoor readings were 231 ng/m^3, 245 μg/g and 73 μg/m^3, for outdoors, respectively indicating PAH and TSP concentrations inside 27 and 18 times greater, respectively than outdoors. With respect to concentrations of individual PAHs (particulate + gas phase), the five highest concentrations were of acenaphthylene (AcPy) (3583 ng/m^3), naphthalene (Nap) (1264 ng/m^3), acenaphthene (Acp) (349 ng/m^3), fluoranthene (FL) (243 ng/m^3) and phenanthrene (PA) (181 ng/m^3). Median values for indoor/outdoor (I/O) ratios of individual PAHs ranged from 5.7 to 387.9, which implied that the temple was a significant PAH source. Moreover, PAH content of the tested stick incense and ash was very low. PAH levels inside the temple were much higher than those measured in the vicinity and inside residential houses; and were in fact close to levels measured at a local traffic intersection in Tainan, Taiwan, and those in a graphite-electrode producing plant during the graphitization process.

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PII: S0304-3894(02)00146-2

It is obvious that such substantially high concentrations of PAHs and TSP constitute a potential health hazard to people working in or visiting the temple.

Keywords: Polycyclic aromatic hydrocarbons (PAHs); Incense; Indoor; Temple; Sources

1. Introduction

In the past few decades, polycyclic aromatic hydrocarbons (PAHs), formed mainly during carbonization and incomplete combustion of organic materials [1], have been widely investigated due to their potentially carcinogenic and mutagenic nature [2,3]. Of special interest are those generated by combustion sources inside houses and workplaces [4–18], such as burning of candles and incense, cigarette smoking, cooking, fuel burning, graphite-electrode production, production of refractories, aluminum reduction, and so on. Additionally, the National Research Council (NRC) in the US reports that people spend more than 80% of their time indoors, where PAH levels may be higher than outdoors [19]. It is thus clear that indoor PAH pollution can be a serious problem. Incense burning, an important rite in daily religious ceremonies for a great percentage of Taiwanese families, and a common and popular practice in most Buddhist and Taoist temples in Taiwan, produces non-stop smoke during the long, slow, and incomplete combustion process. The smoke emitted by incense has been proven to contain PAHs [20] and has also been identified as mutagenic using the Ames test [21]. Therefore, an evaluation of PAH characteristics inside and outside Taiwanese temples is useful in order to assess human exposure to PAHs.

Many researchers, organizations and countries have proposed or promulgated regulations on PAH emissions. Slooff et al. [22] proposed a maximum permissible risk level of 1 ng/m^3 Benzo[a]pyrene (BaP) in ambient air, based on the carcinogenic potential of inhaled particulate PAHs. In Germany, the German technical exposure limit (TRK value) for BaP concentrations in air is 2 μg/m^3 for most workplaces [23]. In the US, the US Environmental Protection Agency has proposed a reference concentration (RfC) of naphthalene (Nap) in ambient air of 3 μg/m^3 to prevent harmful respiratory tract, ocular, and blood effects [24]. The National Institute for Occupational Safety and Health (NIOSH) concluded that occupational exposure to coal products can increase the risk of lung and skin cancer in workers, and recommended an occupational exposure limit for coal tar products of 0.1 mg/m^3 PAHs during a 40-h workweek consisting of 10-h workdays [25]. Moreover, the Occupational Safety and Health Administration (OSHA) has established a legally enforceable limit of 0.2 mg/m^3 of PAHs [25]. Unfortunately, to our knowledge, few relevant PAH standards exist for non-working environments, such as houses and temples.

This investigation characterizes human exposure to PAHs and total suspended particulate (TSP) inside and around a Taiwanese temple, and compares indoor levels and the corresponding outdoor levels. Actual concentrations of these air pollutants thus obtained were also compared with values reported by other researchers and to standards set by various countries and organizations [22,23,25–28]. In addition, three types of unburned sticks and burned ash from incense commonly used in Taiwan were analyzed to investigate correlation between incense type and PAH emissions. Results provide information useful for assessing

health risks and for environmental policy making regarding indoor PAH and TSP pollution caused by incense burning in similar environments.

2. Experimental

2.1. Sampling program

The Taiwanese temple chosen for this study is located in the suburban area of Tainan city in southern Taiwan. This temple is 10 m off the ground and has internal dimensions of 50 m (L) × 20 m (W) × 3.4 m (H). Another sampling site, representing the urban ambient PAH level, was sited on the roof of a four-story building (13 m in height) on the campus of National Cheng Kung University (NCKU) in the center of Tainan city, Taiwan. For indoor and outdoor PAH measurements, sampling work was conducted from 9:00 a.m. to 5:00 p.m. and from 9:00 a.m. to 9:00 a.m. the next day, respectively, for 3 sequential days (2 sequential days for the urban sampling location) during March 1996. In addition, three representative types of incense—aloe wood incense, Taiwan yellow, and Taiwan black, all burned in the temple every day, were cut into three pieces (seven sticks each time) and weighed prior to subsequent solvent extraction and PAH analyses. In addition, incense ash collected from trays were sampled (15 g each time), extracted and analyzed to determine residual PAH content. Characteristics of these samples are listed in Table 1.

2.2. Chemicals

Analytical-reagent grade methanol, dichloromethane, *n*-hexane and acetone (Merck, Germany) were used as solvents. A PAH standard containing 16 PAH compounds (concentration: 100–2000 μg/ml) (Mixture 610-M, Supelco, USA) and five individual PAH compounds (concentration: 10 μg/ml; Merck, Germany) were used to create calibration curves. Twenty-one PAHs, including Nap, acenaphthylene (AcPy), acenaphthene (Acp), fluorene (Flu), phenanthrene (PA), anthracene (Ant), fluoranthene (FL), pyrene (Pyr), cyclopenta[c,d]pyrene (CYC), benz[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[e]pyrene (BeP), BaP, perylene (PER), indeno[1,2,3-cd]pyrene (IND), dibenz[a,h]anthracene (DBA), benzo[b]chrysene (BbC), benzo[ghi]perylene (BghiP) and coronene (Cor), were identified and quantified for each collected sample.

Table 1
Summary of samples

Sampling site or sample	Number of samples	Date of sampling
Inside the temple[a]	6	22–24 March 1996
Outside the temple	6	22–24 March 1996
Urban site	4	11–12 March 1996
Unburned incense	9	18 March 1996
Incense ash	5	22 March 1996

[a] Environmental condition: average relative humidity = 80%; average temperature = 25 °C.

2.3. Sample collection

The sampling system and sampling procedure for ambient air samples were based on a previous study by Lee et al. [29]. Samples were collected using two high-volume semi-volatile samplers (PS-1, General Metal Works Co., USA) with a pump drawing air through a glass fiber filter (10.2 cm in diameter, cat. no. 1820-101, Whatman International Ltd.) to collect particulate PAHs and TSP. The filter was followed by a glass cartridge containing a 5 cm long polyurethane foam (PUF) plug, which in turn was followed by 3 cm thick packing of XAD-2 resin (Sigma), and finally by a 2 cm long PUF plug to collect the gas-phase PAHs. During sample transportation and storage, the PUF plug and resin were stored in clean screw-top jars, each with a Teflon cap liner, and glass fiber filters were placed on a pre-baked glass plate and wrapped with aluminum foil. Glass fiber filters were weighed before and after sampling to determine the amounts of particulate collected. Prior to sampling, glass fiber filters were cleaned with distilled-deionized water and dried in an oven at 450 °C for 8 h. Glass cartridges were cleaned by sequential Soxhlet extractions with distilled-deionized water, methanol, dichloromethane (DCM) and a mixture of *n*-hexane/acetone (50/50, v/v) for 24 h each, and finally dried at 45 °C to remove residual solvent.

2.4. Chemical analysis

For PAH analysis of the samples: after final weighing, all glass fiber filters and glass cartridges were separately placed in appropriate Soxhlet extractors and extracted with a DCM/*n*-hexane mixture (50/50, v/v) for 24 h. The extract was then concentrated under ultra-pure nitrogen, cleaned and re-concentrated to exactly 0.5 ml using a procedure that described by Lee [30]. All extracts were analyzed using a gas chromatograph/mass selective detector (GC/MSD) (GC-5890 with MSD-5972, Hewlett Packard, USA) with an HP Ultra2 capillary column (50 m × 0.32 mm × 0.17 μm, Hewlett Packard, USA). A computer-controlled automatic sampler (Model 3365, Hewlett Packard, USA) was used in conjunction with the GC/MS system. All injections were splitless and volume was 1 μl. Injector and detector temperatures were 300 and 325 °C, respectively. The temperature program used was: an initial fast ramp from 50 to 100 °C at 20 °C/min, followed by a milder ramp from 100 to 290 °C at 3 °C/min, and a soak at 290 °C for 40 min. Recovery efficiency of PAHs ranged from 78 to 95% (average 86%). Method detection limits (MDL) were between 0.025 (BaA) and 0.742 ng (Nap).

3. Results and discussion

3.1. Total-PAH concentrations of selected sources

Total-PAH concentrations (sum of 21 investigated PAHs) in ambient air inside and around the temple, at the urban site, and at an intersection with heavy traffic are presented in Table 2. Total-PAH concentrations in indoor air at the temple ranged from 3349 to 9238 ng/m^3, with a mean of 6258 ng/m^3. This mean total-PAH concentration was approximately 27 times higher than that found outside the temple (231 ng/m^3) and 11.6 times higher than

Table 2
Total-PAH concentrations and particle-bound PAH concentrations in ambient air at selected sampling sites

Sampling site	Total-PAH concentration (ng/m^3)		Particle-bound PAH concentration (μg/g)	
	Range	Mean	Range	Mean
Inside the temple	3349–9238	6258	318–636	490
Outside the temple	183–263	231	188–277	245
Urban site	502–580	541	352–444	398
Traffic source[a]	4500–11,300	8110	5210–29200	15,400

[a] Results reported by Lee et al. (1995) [29].

that at the urban site (541 ng/m^3), and was about 77% of the 8110 ng/m^3 concentration at the traffic-source. Accordingly, the high PAH concentrations measured inside the temple deserve more attention.

3.2. Particle-bound PAH concentrations of selected sources

Particle-bound PAH concentrations (μg/g) was defined as PAH mass (μg) adsorbed on the air particulate and normalized by the particle mass (g). Concentrations in ambient air at selected sampling sites are shown in Table 2. Particle-bound PAH concentrations inside the temple ranged from 318 to 636 μg/g and averaged 490 μg/g. This mean value was twice as high as that found outside the temple (245 μg/g) and 1.2 times the mean at the urban site (398 μg/g). However, the magnitudes of particle-bound PAH concentrations inside and around the temple and at the urban site were in the same order, but much lower than that of the traffic source (15,400 μg/g) cited by Lee et al. [29]. For the temple sampled in the present study, indoor PAH concentrations were comparable with concentrations at the traffic source, whereas particle-bound PAH concentrations were only about 1/30 the level of those found at the traffic source.

3.3. TSP concentrations of selected sources

Table 3 shows that TSP concentrations in indoor air at the temple were between 280 and 1880 μg/m^3, and averaged 1316 μg/m^3. Mean TSP concentration was approximately

Table 3
TSP concentrations in ambient air at selected sampling sites and the National Air Quality Standard (NAQS) in Taiwan for TSP concentrations

Sampling site	TSP concentration (μg/m^3)		
	Range	Mean	NAQS[a]
Inside the temple	280–1880	1316	(1) Yearly geometric mean: 130
Outside the temple	52–95	195	(2) 24-h mean: 250
Urban site	162–228	73	
Traffic source[b]	177–338	255	

[a] National Air Quality Standard (NAQS) promulgated by EPA, Taiwan (1999) [28].
[b] Results reported by Lee et al. [29].

18 times higher than that measured outside the temple (73 μg/m^3), 6.7 times higher than the mean concentration at the urban site (195 μg/m^3) and 5.2 times greater than the mean concentration at the traffic source (255 μg/m^3), respectively. The indoor TSP concentration of the temple clearly exceeded both the yearly geometric mean (130 μg/m^3) and the 24-h mean value (250 μg/m^3) set by the National Air Quality Standard (NAQS) [28] in Taiwan by a wide margin. However, the NAQS quoted here serves only as a reference, since it is a standard for ambient air rather than for indoor air. Nevertheless, these values still suggest that attention is due to TSP pollution as well as PAH pollution inside temples. Comparing the results of TSP concentrations with those of particle-bound PAH concentrations and PAH concentrations (as seen in Tables 2 and 3), a location with high TSP or PAH concentration does not necessarily have high particle-bound PAH concentrations; this observation is worthy of further investigation.

3.4. Individual PAH concentrations of selected sources

Profiles for mean gas-phase individual PAH concentrations in ambient air inside the temple, at the urban site, and at the traffic source are given in Fig. 1. Inside the temple, concentrations of the volatile PAHs (AcPy, (MW) = 152; Acp, (MW) = 154; PA, (MW) = 178; and FL, (MW) = 202) were even higher than those of the traffic source; only naphthalene (Nap, (MW) = 128) concentrations were not higher. Of these, acenaphthylene (AcPy) was the most abundant and the principal PAH component with a mean concentration (±S.D.)

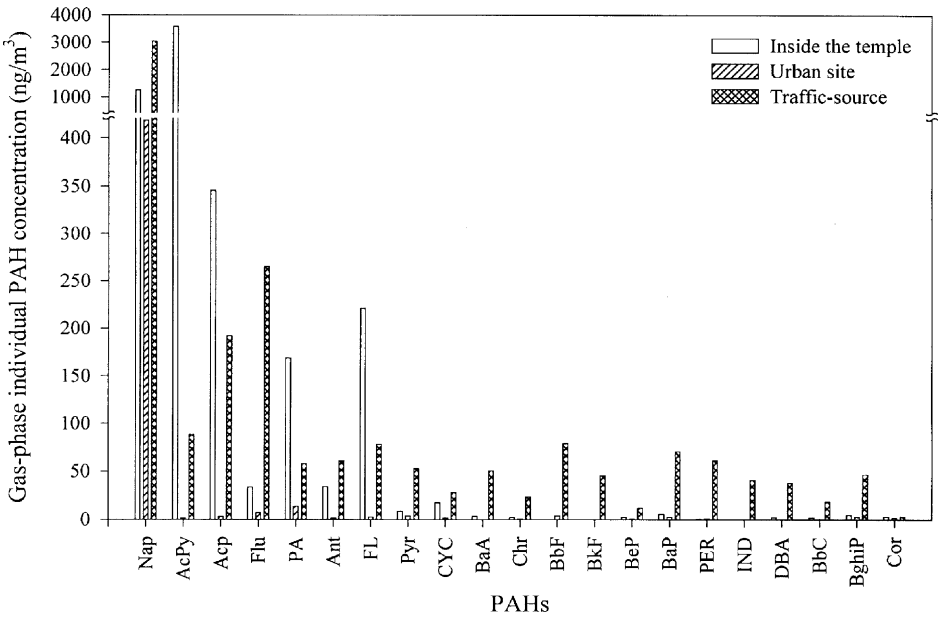

Fig. 1. Profiles of mean gas-phase individual PAH concentrations in ambient air at selected sampling sites (traffic-source data from Wang 1994 [31]).

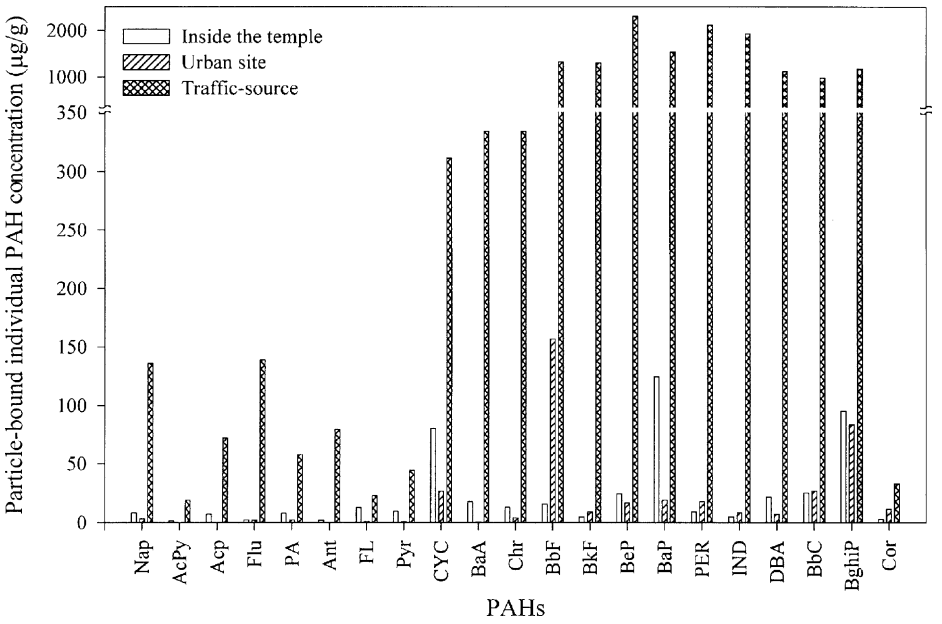

Fig. 2. Profiles of mean particle-bound individual PAH concentrations in ambient air at selected sampling sites (traffic-source data from Wang 1994 [31]).

of $3581 \pm 2189\,ng/m^3$, representing on average 57.2% of total PAHs. Following that were Nap, Acp, FL and PA at 1257 ± 361, 345 ± 259, 221 ± 144 and $169 \pm 127\,ng/m^3$, respectively, while other PAHs had individual mean concentrations below $35\,ng/m^3$. This is a characteristic and unique phenomenon found in indoor air of the temple in the present study. Except in terms of concentrations of the five PAHs mentioned above, the traffic source had markedly higher PAH concentrations than the air inside the temple and at the urban site.

Fig. 2 illustrates the profiles of mean particle-bound individual PAH concentrations ($\pm$S.D.) in ambient air inside the temple, at the urban site, and at the traffic source. Among the particle-bound individual PAH concentrations found inside the temple, the five highest concentrations were of BaP, (MW) = 252; BghiP, (MW) = 276; CYC, (MW) = 228; BbC, (MW) = 278 and BaA, (MW) = 228; at 125 ± 88, 95 ± 20, 80 ± 72, 25 ± 5 and $18 \pm 14\,\mu g/g$, respectively. The mean particle-bound individual PAH concentrations of CYC and BaA were higher than expected since CYC and BaA were not the heaviest PAHs among the 21 investigated. This unique profile serves as an important marker for PAH emissions of Taiwanese incense. However, for all individual PAH compounds, mean particle-bound concentrations inside the temple were much lower than corresponding ones at the traffic source.

3.5. Indoor and outdoor PAH concentrations

The indoor and outdoor PAH concentrations (particulate + gas phase) for the temple site are shown in Table 4, in which Li and Ro's data [10] for five incense-burning homes and 14 mixed residential homes (one smoking household, five incense-burning households,

Table 4
Indoor and outdoor individual PAH concentrations (particulate + gas phase) for the investigated temple, incensed homes and mixed residential homes (ng/m^3)

PAHs	Temple			Incensed homes[a]			Mixed residential homes[b]		
	I[c]	O[d]	I/O[e]	I[c]	O[d]	I/O[e]	I[c]	O[d]	I/O[e]
Nap	1224.3	160.3	8.6	87.1	39.1	2.2	71	36	2.1
AcPy	3186.3	8.4	387.9	[f]	[f]	[f]	[f]	[f]	[f]
Acp	294.9	9.6	28.7	19.3	9.7	1.6	13	9.4	1.3
Flu	29.9	3.5	9.5	30.6	14.6	1.8	23	15	1.4
PA	132.3	4.5	48.3	26.2	20.5	1.2	20	21	1.0
Ant	24.1	0.4	113.2	2.9	1.8	1.4	2.4	2.2	1.1
FL	200.6	1.7	141.8	6.2	5.1	1.1	5.8	6.8	0.8
Pyr	22.7	0.9	25.8	9.5	6.1	1.5	6.5	7.0	0.9
CYC	85.0	0.4	199.0	[f]	[f]	[f]	[f]	[f]	[f]
BaA	19.8	1.4	20.8	9.3	10.4	1.0	7.8	9.0	1.0
Chr	14.5	0.5	53.1	5.0	3.4	1.7	3.5	3.3	1.3
BbF	9.1	0.9	9.7	3.1	2.8	0.9	2.4	3.1	0.8
BkF	4.7	0.7	10.2	1.0	1.1	1.0	0.91	1.1	0.8
BeP	19.1	1.9	9.2	[f]	[f]	[f]	[f]	[f]	[f]
BaP	102.1	10.3	11.1	2.4	1.5	1.7	1.7	1.7	0.9
PER	8.6	1.6	6.3	[f]	[f]	[f]	[f]	[f]	[f]
IND	2.4	0.3	25.0	5.6	4.2	1.5	4.5	4.5	0.8
DBA	22.8	2.4	14.9	3.5	4.1	0.8	2.9	3.3	0.9
BbC	23.1	0.7	46.1	[f]	[f]	[f]	[f]	[f]	[f]
BghiP	90.5	3.7	48.6	7.6	6.4	1.2	5.8	6.7	1.0
Cor	6.5	1.4	5.7	[f]	[f]	[f]	[f]	[f]	[f]

[a] PAH concentrations measured in five incense-burning homes in Taipei, Taiwan by Li and Ro (2000) [10].
[b] Geometric means of PAH concentrations in 14 mixed residential homes (one smoking household, five incense-burning households, and eight households without smoking or incense-burning) in Taipei, Taiwan by Li and Ro (2000) [10].
[c] Geometric mean of individual-PAH concentration indoors.
[d] Geometric mean of individual-PAH concentration outdoors.
[e] Median of indoor-to-outdoor ratio.
[f] Data not reported by Li and Ro (2000) [10].

and eight households without smoking or incense-burning) are included for comparison. Indoor PAH levels for homes where incense is burned and for mixed residential homes were comparable, and both were much lower than levels at the temple. This is not surprising because traditionally, in Taiwanese homes where incense is burned, a group of only 2–6 incense sticks is burned at a time during morning and evening worship, with an average burn-time of approximately 40 min. In contrast, tens or, in the case of major ceremonies, occasionally hundreds of incense sticks are kept burning for several hours or even longer every day in most temples.

For PAHs indoors, naphthalene had the highest concentrations for both incense-burning homes and mixed residential homes, while acenaphthylene was most abundant in the temple samples.

Huynh et al. [6] reported that incense burning was linked to emissions of FL, Pyr, BaP and BghiP. In the present study, the temple samples likewise had higher concentrations

of FL, Pyr, BaP and BghiP. Meanwhile, results also showed higher concentrations of AcPy, Acp, PA, Ant, CYC, Chr and BbC not reported by Huynh et al. [6]. This result implies that characteristic PAHs emitted from incense burning are not limited to FL, Pyr, BaP and BghiP. Indeed, compared with people living inside incense-burning homes or mixed residential homes, people working inside or visiting a temple are exposed to extremely high concentrations of a variety of PAHs as seen in Table 4. With respect to the relationship between indoor and outdoor PAHs, indoor levels were all significantly higher than the corresponding outdoor ones at the temple site. Furthermore, for each PAH studied, the five highest ratios of indoor/outdoor (I/O) concentrations were for AcPy (387.9), CYC (199.0), FL (141.8), Ant (113.2) and Chr (53.1), in that order. For the temple, incense-burning homes and mixed residential homes, median values of all I/O ratios (calculated for each individual PAH), were in the ranges of 5.7–387.9, 0.8–2.2 and 0.8–2.1, respectively. In addition, Chuang et al. [32] and Mitra and Ray [33] suggested that I/O ratios higher than three indicate that PAHs were generated inside the domestic environments. The findings in the present study are seemingly consistent with that claim.

3.6. Comparison of PAH concentrations and selected air quality standards

The implication of human exposure to mixtures of PAHs, rather than to individual substances, is important. Occupationally or environmentally, people are seldom exposed to a single PAH compound, but rather to a mixture of PAHs. In spite of this, BaP concentration is still a great concern because BaP has been shown to be a potent carcinogen in studies on laboratory animals, has been very extensively documented and is readily measured. In addition, BaP is often used as a marker for total PAH exposure in industry and in the environment. Table 5 shows a comparison of total-PAH and BaP concentrations for various emission sources and the PAH standards. BaP concentrations (71.5–124.2 ng/m^3) measured inside the temple were much higher than those inside California residential homes where tobacco was smoked (2.2 ng/m^3) and those without a specific indoor combustion source (0.83 ng/m^3) [26]. It also exceeded the ambient BaP levels reported for cities near aluminum smelters in Canada (3–49 ng/m^3) [27], and was comparable with concentrations recorded during the graphitization process in a graphite-electrode producing plant (10–330 ng/m^3) [14]. In addition, indoor BaP concentrations measured largely exceeded the maximum permissible risk level (1 ng/m^3 BaP) for ambient air suggested by Slooff et al. [22] based on the carcinogenic potential of inhaled particulate PAHs. However, levels of measured indoor BaP concentrations did not exceed the TRK value for workplaces except for pencil pitch production (2000 ng/m^3) [23]. Furthermore, mean total-PAH concentration was approximately 1/32 of the legally enforceable limit (0.2 mg/m^3) established by the OSHA [25], and 1/16 of the occupational exposure limit (0.1 mg/m^3 for a 10-h workday, 40-h workweek) recommended by the NIOSH [25] for coal tar production.

3.7. PAH content in selected Taiwanese incense sticks and ash

PAH content values (ng/g) for various selected Taiwanese incense sticks and ash are presented in Table 6. Among the three types of incense tested—Taiwan yellow, Taiwan

Table 5
Comparison of total-PAH and BaP concentrations for various emission sources and PAH limit values (ng/m^3)

Emission sources or PAH limit values	BaP concentration	Mean total-PAH concentration	Literature
Various emission sources			
Incense burning[a]	71.5–124.2	6,258	This study
Homes with tobacco smoking[b]	2.2		[26]
Homes without specified indoor combustion sources[b]	0.83		[26]
Ambient air for cities near aluminum smelters[c]	3–49		[27]
Graphitization process[d]	10–330		[16]
PAH limit values			
Ambient air[e]	1		[22]
Workplaces excluding pencil pitch production (DFG)[f]	2000		[23]
Coal tar production (OSHA)[g]		200,000	[25]
Coal tar production (NIOSH)[h]		100,000	[25]

[a] Concentrations were 8 h averages and measured inside a temple.
[b] Concentrations were 24 h averages.
[c] Reported for cities near aluminum smelters in Canada.
[d] Arithmetic means of 12 stationary air measurements during graphitization process in a graphite-electrode producing plant.
[e] Maximum permissible risk level of BaP in the ambient air.
[f] German technical exposure limit (TRK value).
[g] A legally enforceable limit established by OSHA.
[h] An occupational exposure limit recommended by NIOSH for a 10-h workday, 40-h workweek.

black and aloe wood—Taiwan black had the highest PAH content (6189.3 ng/g), followed by Taiwan yellow (2523.0 ng/g) and aloe wood (744.5 ng/g). The fact that Taiwan black contains large amounts of carbon black may help explain the above result. However, the present study did not include sufficient analysis to conclude that Taiwan black emits more PAHs than all other types of incenses. In addition, large variations, including variation in principal compounds and their concentrations, were observed because different types of incense sticks were made from different bamboos, spice powders and resins. In order to produce incense sticks that burn with a fragrant odor, spice grains are coated onto thin bamboo sticks with resins. The most commonly used raw materials are Glycyrrhiza, Cinnamomun, Ocimum, Nardostachys, Foeniculum, Rheum, Radix, Asarum, Magnolia, Eugenia, Lysimachia, Juniperus, Liquidambar, and Santalum. However, firm correlations between these raw materials and PAH emissions require further investigation.

Compared with the results of particle-bound PAH concentrations (Table 2), the concentrations of PAHs found in incense ash seem much less significant. Moreover, apart from BbF with a concentration almost twice as high as the next-most-abundant PAH CYC, PAHs with concentrations above 100 ng/g in the ash were spread out through rings from 2 to 6 (Table 6).

Table 6
PAH content in the selected Taiwanese stick incenses and the incense ash (ng/g)

Compound	Type of Taiwanese incense							
	Taiwan yellow		Taiwan black		Aloes wood		Incense ash	
	Mean	S.D.[a]	Mean	S.D.	Mean	S.D.	Mean	S.D.
Nap	36.3	4.5	65.0	2.2	43.5	3.1	126.3	61.5
AcPy	498.6	79.1	1167.1	77.5	4.6	2.2	16.9	21.6
Acp	108.0	17.4	19.7	2.5	70.5	5.4	47.6	60.3
Flu	1266.0	334.2	22.0	0.9	15.8	2.8	7.1	4.0
PA	66.2	7.8	11.3	0.7	58.2	5.7	342.7	74.0
Ant	206.4	70.6	22.6	6.0	12.9	0.7	60.1	9.6
FL	118.5	13.5	313.0	10.6	48.3	2.7	162.4	48.2
Pyr	56.5	4.0	907.9	90.6	49.5	3.6	189.0	43.7
CYC	25.2	8.5	1701.3	185.2	50.3	5.0	390.0	279.5
BaA	16.8	1.2	93.6	3.7	16.8	0.7	207.7	184.1
Chr	19.0	1.5	408.6	170.4	8.9	0.5	233.4	53.3
BbF	10.6	0.7	33.2	13.2	28.3	2.7	701.7	419.2
BkF	0.8	0.1	10.5	2.8	9.3	0.5	59.8	32.7
BeP	1.2	0.4	3.6	2.3	3.4	2.3	13.1	4.8
BaP	9.9	3.2	161.4	15.6	15.8	2.0	274.2	35.4
PER	1.2	0.2	5.9	4.5	3.6	2.3	45.1	17.2
IND	6.1	2.2	13.5	4.6	4.9	1.2	51.8	24.2
DBA	2.3	0.9	61.9	28.6	1.8	0.5	114.3	103.6
BbC	66.0	18.7	447.2	52.6	283.9	260.1	200.0	52.6
BghiP	6.4	2.0	549.2	64.1	14.3	0.9	231.7	25.1
Cor	2.0	0.9	170.3	60.5	ND[b]	ND	7.4	2.2
Total-PAH[c]	2523.0	412.4	6189.3	362.8	744.5	278.6	3482.3	303.1

[a] S.D.: standard deviation.
[b] ND: not detected.
[c] Total-PAH = sum of 21 PAHs.

4. Conclusions

Of the indoor airborne PAHs detected in the temple, about 90% were in the gas phase. Consequently, particle-bound PAH concentrations inside the temple are not much different from those measured outside the temple and at the urban site. However, PAH and TSP concentrations measured inside the temple exceeded outdoor concentrations by factors of 27 and 18, indicating that the temple was clearly a significant source of PAHs.

In addition to the four characteristic PAHs reported by Huynh et al. [6] for incense burning, high levels of AcPy, AcP, PA, and CYC were also found inside the temple, suggesting that the composition of PAHs emitted from incense burning varies greatly due to differences in the raw materials used in incense-making.

The burning of incense may provide some spiritual or physical comfort. However, if not properly vented, the accumulated high levels of PAHs inside a temple or house may become a potential threat to humans. Likewise, attention should be paid to the proper disposal of

incense ash. Without proper treatment, a great amount of mutagenic PAHs can be released to the environment.

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