Indoor PM$_{2.5}$ and its Polycyclic Aromatic Hydrocarbons in Relation with Incense Burning

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Abstract. This study aims to determine fine particulate matter (PM$_{2.5}$) and polycyclic aromatic hydrocarbons (PAHs) emitted from incense burning to assess human health risk. PM$_{2.5}$ samples were collected for 8 hrs and 24 hrs during special occasions and normal period from two shrines in the city of Chiang Mai, Thailand. PM$_{2.5}$ bound PAHs were extracted and analyzed by GC-MS. The highest average PM$_{2.5}$ concentrations were found during Chinese New Year (625±147 µg/m$^3$ (8 hrs) and 406±159 µg/m$^3$ (24 hrs)). The highest total PAHs concentrations were also found during the same period (168±60 ng/m$^3$ for 8 hrs and 102±26 and for 24 hrs). Concentrations of PM$_{2.5}$ and carcinogenic-PAHs were highly correlated ($r$ = 0.451-0.802) and were high during special occasions particularly during Chinese New Year due to high number of visitors and amount of incense being burned. The toxicity equivalent (TEQ) values were also relatively high during Chinese New Year (31-32 ng/m$^3$ (8 hrs) and 10-20 ng/m$^3$ (24 hrs)). It can be revealed that incense burning emits air pollutants and can increase degree of indoor air pollution and human health risk.

1. Introduction
The polycyclic aromatic hydrocarbons (PAHs) are comprised of a group of semi-volatile organic pollutants containing at least two fused aromatic rings. PAHs are toxic chemical group, which some of them are mutagenic or carcinogenic. The percentage of carcinogenic PAHs bound to PM$_{10}$, PM$_{2.5}$ and PM$_{1.0}$ emitted from vehicles and natural gas combustion in descending order were PM$_{1.0}$ (49-56%) > PM$_{2.5}$ (37-43%) > PM$_{10}$ (35-41%). Therefore, PAH’s concentrations associated with particulate matters are highly dependent on fine particles [1]-[3]. Furthermore, Hassanvand et al. [3] revealed the predominant PM-bound PAHs concentrations found in PM$_{2.5}$ were 83-88 %, which can penetrate deep into the alveolar regions of the lungs.
An epidemiological study found the relationship of traffic-related PM$_{2.5}$-bound PAHs and odd preterm birth was increased by 30 % per inter-quartile increase, which positively correlated and clustered together with the analysis [4]. Moreover, several studies assessed human exposure to airborne PMs and PAHs from heavy incense burning. The long-term exposure to incense burning in homes was associated with an increased risk of cardiovascular mortality [5], while Wang et al. [6] reported...
incense burning at home was associated with an increased risk of asthma and wheezing. However, incense burning is a popular practice inside temples more than residential homes and the workplace. Chiang et al. [7] investigated the assessment of probabilistic human health risk exposed to carcinogenic PAHs in particles emitted from incense burning for temple goers/workers in a Taiwanese temple. A 95% probability total ILCR (9.87×10^{-4} to 1.13×10^{-3}) of workers extremely exposed to carcinogenic PAHs in the temple were indicated to be of a high potential health risk.

Incense burning is a serious issue concerning human health effect. The purpose of this study has been to provide reliable data and information concerning incense burning and its pollutant emissions. Consequently, the main objective of the research is to determine PM$_{2.5}$-bound PAHs emitted from incense burning to assess health risks.

2. Materials and methods

2.1 PM$_{2.5}$ sampling

The sampling shrines are located in Waroros market, which is one of the most crowded areas in the city of Chiang Mai (Figure 1). The first shrine is the oldest shrine. The size of the building is approximately 8x18 m$^2$ and 4 m height. The ventilation system is not well-equipped and the building was designed as almost a closed system with only one door open for visitors. The second shrine has an area of approximately 960 m$^2$. The ventilation system in the second shrine is better than the first one. It has 4 turbine ventilators on the roof of the worship room and its ceiling is open. It has quite a good ventilation system. At the first shrine, each visitor would purchase 8 large incense sticks (~ 9 mm diameter, ~ 48 cm long and ~ 34 cm coated combustible part). After each individual ceremony, the burned incense sticks are not allowed to be kept inside the worship area, but are kept outside. The second shrine would purchase a package of 28 smaller incense stick. Twenty – six of them were burned in the worship room and the rest were burned outdoors.

Indoor PM$_{2.5}$ samples were collected on Teflon fiber filters (2 µm PTFE, 46.2 mm diameter, Whatman’s filter paper) using Minivol Air Samplers (Air metric, USA) at a flow rate of 5 L/min for 8 hrs (8 am – 4 pm) and 24 hrs (8 am – 8 am). The filters were pre-weighed by a microbalance in a controlled room (25.4±2.8 °C, 41.3±5.4% RH). After the sampling, the filters were kept in aluminium foil plates inside a desiccator for 48 h before being re-weighed and stored in a freezer (-4.0 °C) until analysis.

The sampling was carried out during special occasions and over normal periods (the background value). The special occasions were those associated with the Chinese lunar calendar, such as Chinese New Year, the Chinese Ghost festival, a vegetarian festival, the moon festival.

2.2 Extraction and analysis of PAHs

The samples were extracted in 25 ml dichloromethane (DCM) and n-hexane mixture (1:1, v/v) for 45 min by a ultrasonicator. The extracted solutions were than purified using a nylon syringe filter and were dried using a rotary evaporator. The solution was added with a mixture of internal standards (acenaphthene-d12 and pyrylene-d10) and was adjusted to 2 ml volumetric flask with solvent mixture. PAHs were analyzed by gas chromatography - mass spectrometer (GC-MS, Agilent, USA) equipped with a 30 m HP-5MS capillary column. The heating program was set for column oven from 60˚C to 290˚C at 6 ˚C/min, then hold for 20 min [8]. The MS was operated in selective ion monitoring mode (SIM). The 16-PAHs was identified and quantified including naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACE), fluorene (FLU), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLA), pyrene(PYR), benz[a]anthracene (BaA), chrysene(CHR), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene(BkF), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (IND), dibenzo[a,h]anthracene(DBA), benzo[g,h,i]perylene (BPER). The quality control of PAHs was studied using standard reference material (SRM 1649b; urban dust, NIST, USA) Recovery efficiency of PAHs (n=3) ranged 61 (CHR) to 126 (ANT) % and averaged 84 %. The detection limit in this study were 0.08 – 0.66 ng/m$^3$. 


3. Results and discussions

3.1 Concentrations of \( PM_{2.5} \) and \( PM_{2.5} - \) bound PAHs

Concentrations of indoor \( PM_{2.5} \), measured on special occasions (with exclusion of Chinese New Year), Chinese New Year and the normal period at both shrines are shown in Table 1. The normal period of 8 hrs of indoor \( PM_{2.5} \) ranged from 82±25 µg/m\(^3\) (shrine 1) to 100±35 µg/m\(^3\) (shrine 2), while those of the 24 hrs periods were 50±20 µg/m\(^3\) (shrine 2) to 52±24 µg/m\(^3\) (shrine 1). Concentrations of \( PM_{2.5} \) at shrine 1 were slightly lower than those at shrine 2, but no significant difference \((p>0.05)\). Based on the results, the different architecture of the two shrines might not play a significant role for \( PM_{2.5} \) concentrations. Otherwise, if the number of visitors is almost equal, the \( PM_{2.5} \) concentrations in the shrine 1 should be higher than the shrine 2 due to its poorer ventilation system. In general at both shrines, the mean \( PM_{2.5} \) concentrations of 8 and 24 hrs in normal period were significantly less than those of the Chinese New Year and other special occasions \((p>0.05)\). The highest value of indoor \( PM_{2.5} \) concentrations was obtained in Chinese New Year for both of 8 and 24 hrs periods (524 ± 110 - 625 ± 147 µg/m\(^3\)) and 317 ± 109 - 406 ± 159 µg/m\(^3\) at the two shrines. The \( PM_{2.5} \) concentrations associated with number of visitor are highly dependent on the amount of incense being burned \([9]\). During the Chinese New Year and on other special occasions, the 24 hrs average values of \( PM_{2.5} \) (35 µg/m\(^3\)) collected from both shrines were 1-11 times higher than standard value of the National Ambient Air Quality Standard (NAAQS), USA \([10]\). Moreover, it was found that the 24 hrs of incense burning in this study was 2-11 times higher than urban traffic site (28±6.3 - 38±13 µg/m\(^3\)) in Greece \([1]\). The main reason for high level of pollutants found indoors was clearly from number of visitors, which was related with the amount of incense being burned.

Table 2 shows the mean of total PAHs (t-PAHs) bounded with \( PM_{2.5} \) concentrations. Mean t-PAHs of 8-hrs sampling time at shrine 1 were 168±60 ng/m\(^3\) (Chinese New Year), 107±45 ng/m\(^3\) (other special occasions) and 62±30 ng/m\(^3\) (normal period), while those of 24-hrs in Chinese New Year, other special occasions and normal periods were 102±26 ng/m\(^3\), 47±7 ng/m\(^3\) and 32±19 ng/m\(^3\), respectively. At shrine 2, the 8-hrs mean concentrations of total \( PM_{2.5} \)-bound PAHs were 90±41 ng/m\(^3\) (Chinese New Year), 71±50 ng/m\(^3\) (Other special occasions) and 25±15 ng/m\(^3\) (Normal period). The 24-hrs mean PAHs concentrations in all periods at both shrines were lower than those of 8-hrs (46±29 ng/m\(^3\), 30±12 ng/m\(^3\) and 14±9 ng/m\(^3\), respectively). However, the trend of PAHs concentrations found in each occasion was the same. The 8- and 24-hrs of total PAHs concentrations in Chinese New Year were...
higher than those in the other special occasions and normal period. The values were significantly different between the other special occasions and normal period, while the values of the other special occasions were not significantly different from Chinese New Year. The dominant PAHs found in both shrines were BbF, BaP, IND and BPER, while the dominant particulate-bound PAHs collected at Thai temple in Samutprakarn, Chachengsao and Ayuthaya province were BaA, BbF, BaP and DbA [11]. Moreover, 8-hrs indoor BaP concentrations measured during Chinese New Year and other special occasions (1.61 – 10.0 ng/m$^3$) were higher than the values measured by personal samplers from workers in Thai temple (2.53±0.83 ng/m$^3$) [11]. This is probably due to the amount of incense being burnt during the sampling period.

**Table 1** Mean of indoor PM$_{2.5}$ concentrations (µg/m$^3$) in both shrines in various occasions

| Sampling periods       | Shrine 1          | Shrine 2          |
|-----------------------|-------------------|-------------------|
|                       | 8 hrs             | 24 hrs            | 8 hrs             | 24 hrs            |
| Chinese New Year      | 524 ± 110$^a$ (n=2) | 317 ± 109$^a$ (n=6) | 625 ± 147$^a$ (n=3) | 406 ± 159$^a$ (n=6) |
| Other special occasions| 228 ± 81$^a$ (n=5)  | 178 ± 81$^a$ (n=8)  | 184 ± 85$^b$ (n=9)  | 133 ± 71$^b$ (n=8)  |
| Normal period         | 82 ± 25$^b$ (n=7)  | 52 ± 24$^b$ (n=8)  | 100 ± 35$^b$ (n=9)  | 50 ± 20$^c$ (n=13)  |

$^a$, $^b$, $^c$ = Significant differences (p < 0.05) among groups of sampling periods (vertical direction)

**Table 2** Concentrations (ng/m$^3$) of t-PAHs, c-PAHs and nc-PAHs in both shrines in various occasions

| Sampling sites | Sampling periods | Concentrations (Mean±SD) |
|----------------|------------------|-------------------------|
|                |                  | t-PAHs | c-PAHs | nc-PAHs |
| Shrine 1       | Chinese New Year | 168±60$^a$ (n=2) | 83±35$^a$ | 85±25$^a$ |
|                | Other special occasions | 107±45$^ab$ (n=5) | 55±31$^ab$ | 52±16$^{ab}$ |
|                | Normal periods   | 62±30$^b$ (n=7) | 24±15$^b$ | 38±12$^b$ |
| Shrine 2       | Chinese New Year | 90±41$^a$ (n=3) | 64±34$^a$ | 26±9$^a$ |
|                | Other special occasions | 71±30$^a$ (n=9) | 48±24$^a$ | 22±8$^a$ |
|                | Normal periods   | 25±15$^b$ (n=10) | 15±12$^b$ | 10±7$^b$ |

$^a$, $^b$, $^c$ = Significant differences (p < 0.05) among groups of sampling periods (vertical direction)

The average concentrations of carcinogenic PAHs (c-PAHs) and non-carcinogenic PAHs (nc-PAHs) are shown in Table 2. The c-PAHs were BaA, CHR, BkF, BbF, BaP, IND and DBA while nc-PAHs were NAP, ACY, ACE, FLA, PHE, ANT, FLU, PYR and BPER [10]. The concentrations of c-PAHs and nc-PAHs were found to have the same trend as PM$_{2.5}$ concentrations. The 8- and 24-hrs average c-PAHs concentrations at both shrines in descending order were Chinese New Year > other special
occasions > normal period. However, they were not significantly different \((p>0.05)\) between Chinese New Year and other special occasions but significantly higher than normal period. Moreover, the c-PAHs concentrations of both 8- and 24-hrs samplings were about 1-2 times higher than those of nc-PAHs in every occasion including normal period. The c-PAHs were found in high concentrations because high molecular weight PAHs (>200) could be more easily adsorbed to particulate phase [12].

## 3.2 Correlations between PM\(_{2.5}\) and PAHs

The Spearman’s rank-correlation of PM\(_{2.5}\), t-PAHs, c-PAHs and nc-PAHs concentrations are shown in Table 3. PM\(_{2.5}\) concentrations were significantly correlated \((p<0.01)\) with concentrations of t-PAHs \((r = 0.674-0.822)\), c-PAHs \((r = 0.618-0.802)\) and nc-PAHs \((r =0.612-0.914)\). Moreover, the strong positive correlations between PM\(_{2.5}\) and all type of PAHs were found in 24 hrs sampling \((r = 0.674-0.822 (t-PAHs), 0.618-0.700 (c-PAHs) and 0.738-0.914 (nc-PAHs))\). The correlation between t-PAHs and c-PAHs \((r = 0.934 -0.982)\) was higher than that between t-PAHs and nc-PAHs \((r = 0.795-0.956)\).

The result obtained indicated that PAHs concentrations associated with fine particles are highly dependent on the number of incense being burned.

### Table 3 Correlations of PM\(_{2.5}\) and PAHs concentrations for 8-hrs and 24-hrs sampling at both shrines

|                  | 8 hrs (n = 14) |                  | 24 hrs (n = 22) |                  |
|------------------|----------------|------------------|-----------------|------------------|
|                  | PM\(_{2.5}\)   | t-PAHs           | c-PAHs          | nc-PAHs          |
| **Shrine 1**     |                |                  |                 |                  |
| PM\(_{2.5}\)     | 1.000          | 0.688**          | 0.802**         | 0.612**          |
| t-PAHs           |                | 1.000            | 0.934**         | 0.956**          |
| c-PAHs           |                | 0.822**          | 1.000           | 0.851**          |
| nc-PAHs          | 0.612**        | 0.956**          | 1.000           | 0.791**          |

|                  | 24 hrs (n = 22) |                  |                  |
| PM\(_{2.5}\)     | 1.000          | 0.822**          | 0.700**          |
| t-PAHs           | 0.674**        | 0.942**          | 0.921            |
| c-PAHs           | 0.700**        | 0.942**          | 0.942**          |
| nc-PAHs          | 0.700**        | 0.942**          | 0.942**          |

**Correlation is significant at the 0.01 level (2-tailed)**

*Correlation is significant at the 0.05 level (2-tailed)

## 3.3 Assessment of possible health effects based on PAHs concentrations

### 3.3.1 Toxicity equivalent (TEQ)

The toxicity equivalent concentration (TEQ) is widely used to assess risk of carcinogenic potency of each individual PAH. This parameter is calculated from total of individual concentration of each PAH multiply by their toxic equivalent factor (TEF) relative to the carcinogenic potency of BaP (Eq.1), which was used as a reference carcinogenic compound [13].

\[
\text{TEQ} = \sum_i (\text{PAH}_i \times \text{TEF}_i) \quad (\text{Eq} \ 1)
\]

Where \(\text{PAH}_i\) is concentration of an individual PAHs and \(\text{TEF}_i\) is the toxic equivalent factor.

Table 4 shows the values of TEQ of each sampling period. TEQ values obtained from both shrines in descending order were Chinese New Year > other special occasions > normal periods. The highest TEQ values were found during Chinese New Year. The mean TEQ values obtained in during Chinese New Year were 2-3 times higher than the normal periods, and 1-2 times higher than other special occasions. In comparison with the study in Taiwan [14], where PM\(_{10}\) samples were collected for 8 hours in a shrine, the TEQ value \((36.6 \text{ ng/m}^3)\) was almost the same with the value obtained during the Chinese New Year in this study \((3.2\pm 1.8 \text{ to } 31.8\pm 27.4 \text{ ng/m}^3)\), while the 8-hrs TEQ values \((0.29\pm 0.12\text{ ng/m}^3)\)
to 4.60±1.35 ng/m$^3$) from Thai temple were lower than in this study [10]. The TEQ values found in this study were much higher than the European guideline (1 ng/m$^3$).

Table 4 Average concentration (ng/m$^3$) of toxicity equivalent (TEQ) and the inhalation cancer risk of PM$_{2.5}$-bound PAHs at shrines in various occasions

| Index | Sites | sampling hours | Chinese New Year | Other special occasions | Normal periods |
|-------|-------|----------------|------------------|------------------------|---------------|
|       | Shrine 1 | 8   | 32±12 | 20±14 | 14±12 |
| TEQ   |     | 24   | 20±7 | 12±3 | 7±5   |
|       | Shrine 2 | 8   | 32±27 | 15±8 | 3±2 |
|       |     | 24   | 10±4 | 7±4 | 3±2 |
|       | Shrine 1 | 8   | 27×10$^{-4}$ | 18×10$^{-4}$ | 12×10$^{-4}$ |
| ICR   |     | 24   | 18×10$^{-4}$ | 10×10$^{-4}$ | 60×10$^{-5}$ |
|       | Shrine 2 | 8   | 28×10$^{-4}$ | 13×10$^{-4}$ | 28×10$^{-5}$ |
|       |     | 24   | 85×10$^{-5}$ | 60×10$^{-5}$ | 23×10$^{-5}$ |
|       | Shrine 1 | 8   | 2,700 | 1,800 | 1,200 |
| Risk  (ICR×10$^6$) |     | 24   | 1,800 | 1,000 | 600 |
|       | Shrine 2 | 8   | 2,800 | 1,300 | 280 |
|       |     | 24   | 850 | 600 | 230 |

The TEQ values of 8-hrs sampling were higher than those of 24-hrs sampling. Both values presented similar trends. Moreover, the TEQ values (8- and 24-hrs) at shrine 2 were lower than shrine 1. However, the obtained TEQ values emitted from motor vehicles and fuel burning for heating found in studied by [15], [16], were lower than those values Chinese New Year of this study. The main factors should be the ventilation system and the amount of incense being burned.

3.3.2 The inhalation cancer risk (ICR) assessment

The inhalation cancer risk (ICR) was used to estimate the value of cancer risk from PAHs exposure during different periods and can be calculated using Equations 2 [8], [15], [17], [18].

$$ICR = TEQ \times IUR_{BaP} \quad (Eq \ 2)$$

Where, $IUR_{BaP}$ is the inhalation unit risk

$IUR_{BaP}$ values for lifetime (70 years) PAHs exposure were used in this study to estimate the inhalation cancer risk. The recommended $IUR_{BaP}$ of the World Health Organization (WHO) is $8.7 \times 10^{-5}$ m$^3$/µg [19]. The mean TEQ value was obtained from the calculation of each period (Eq. 1). The inhalation cancer risk was calculated and compared among different periods as shown in Table 4. The 8- and 24-hrs of lifetime inhalation cancer risks (ICR) calculated based on WHO guideline obtained from both shrines in descending order were Chinese New Year > other special occasions > normal periods. Hence, if a million people were exposed to PAHs at the level of 10 ng/m$^3$ for 70 years, 850 persons may have a risk of cancer development. The ICR values between 10$^{-6}$ to 10$^{-5}$ are potential risk and ICR of 10$^{-6}$ represents a lower-bound zero risk, while the upper 10$^{-4}$ of ICR indicates high potential health risk [17], [20]. The calculated ICR values were found to have a high potential health risk based on WHO, while those based on CalEPA were in a lower-bound zero risk. The societal inhalation cancer risk was obtained by multiplication of ICR values with a million people [15]. The societal inhalation cancer risk was obtained by multiplying the ICR by one million people. The
societal ICR (cases/million people) based on WHO for 8-hrs value calculation at shrines 1 and 2 in descending order were Chinese New Year (2,700 and 2,800), other special occasions (1,800 and 1,300) and the normal periods (1,200 and 280). While those of the societal ICR for 24-hrs calculation in descending order were Chinese New Year (1,800 and 850), other special occasions (1,000 and 600) and the normal periods (600 and 230). The 24-hrs average value for the normal periods in this study was 600 or 8.6 cases/year (shrine 1) and 230 or 3.3 cases/year (shrine 2). In general, the values of societal ICR in all cases were found to be higher at shrine 1 than shrine 2. The main reason might be the poor ventilation system in the shrine 1. The societal ICR values of 8-hrs sampling calculated were higher than the 24-hr sampling due to the service period of the shrine. Generally, the shrines are ordinarily opened in the daytime (8 am – 5 pm) except only during Chinese New Year, when the shrines are opened all the time. However, it should be noted that the values are only a rough estimation of cancer risk from the PM$_{2.5}$-bound PAHs inhalation.

4. Conclusions
The highest indoor PM$_{2.5}$ and PAHs concentrations were found during Chinese New Year due to number of visitors and amount of incense being burned. PM$_{2.5}$ concentrations were highly correlated with c-PAHs indicated that carcinogenic compounds were dominant in particulate PAHs and generated from incense burning. It can be concluded that amount of incense being burned plays a significant role in amount of emitted pollutants and degrees of air pollution and human health risk. To improve indoor air quality, where a lot of incenses are used, the ventilation systems should be equipped to improve air circulation. In public places such as temples and shrines, the number of incenses to be burned by individual visitor should be strictly controlled, while the outdoor air circulation and indoor ventilation system should be ensured to be adequate for such practice.

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