Aerosol and Air Quality Research, x: 1–8, xxxx

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2016.04.0146

Characteristics of Exposure to Particles due to Incense Burning inside Temples in Kanpur, India

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ABSTRACT

Incense burning in temples is a common and popular ritual in India and other Asian countries. This study aims at assessing the quantity and size segregated distribution of particulate matter in temples of Kanpur city, India. Active air sampling was performed in three temples using the Micro Orifice Uniform Deposit Impactor (MOUDI). PM_{10} mass concentrations as high as 2184 μg m^{-3} were recorded inside the temples. Mass concentration values for all samples exceeded the Central Pollution Control Board (CPCB) National Ambient Air Quality Standard (NAAQS) of 100 μg m^{-3}. Particle counts were high, and more than 99% of the numbers of particles generated were $PM_{2.5}$. Particle coagulation is an active mechanism leading to formation of polydispersed particles. Most abundant particles occur in the accumulation mode (dp < 1 μm). Ventilation conditions and amount of incense burned are major factors affecting particle size distribution. Exposure through inhalation, to critically high concentrations of fine particulate matter generated via incense smoke especially for worshippers who frequent the temple and temple workers, raises health concerns. The results clearly indicate that incense smoke is a major source of particulate matter in the temple microenvironment and their chemical characteristics need further examination.

Keywords: Indoor air quality; Incense burning; MMAD; Most abundant PM size.

INTRODUCTION

People spend greater than 80% of their time in indoor environments and Indoor air pollution is the second largest killer in India after high blood pressure (Lomborg, 2014). Necessity to evaluate indoor air quality (IAQ) in terms of contaminant levels in different microenvironments to enable total human exposure is now well recognized (Koistinen *et al.*, 2001; Hoek *et al.*, 2008; Delgado-Saborit *et al.*, 2011; Tan *et al.*, 2012).

Particle size distribution in indoor environments is dominated by fine and ultrafine particles (Jai Devi *et al.*, 2009) and lead to potential health risks (Chiang *et al.*, 2009). Incense burning, which is an incomplete combustion process, is known to emit fine and ultrafine particles in large quantities (Ji *et al.*, 2010), along with Carbon Monoxide (CO), Nitrogen Oxides (NO_x), toxic Polycyclic Aromatic Hydrocarbons (PAHs) and Volatile Organic Compounds (VOC) like benzene and isoprene (Koo *et al.*, 1994; Li and Ro, 2000; Chuang *et al.*, 2013).

Fine and ultrafine particles, because of their small size, can penetrate deep into the respiratory tract and even cross biological barriers, leading to adverse health effects (Ibald-Mulli *et al.*, 2002). They may also act as efficient carriers of toxic compounds (mutagenic in nature, such as PAHs) into the pulmonary alveoli (Kawanaka *et al.*, 2009), which can result in lung cancer (Dennekamp *et al.*, 2001). Incense smoke contains chemical substances that may cause health risks, which include acute effects like irritation to the eyes, nose or throat. On long-term exposure, the effects could be contact dermatitis or worse (Eggert and Hansen, 2004). Research on the physical and chemical properties of particles from incense burning is of growing interest (See *et al.*, 2007; Wang *et al.*, 2007; Kuo *et al.*, 2016).

Incense burning mainly occurs in temples (Lung *et al.*, 2003), churches (Weber, 2006), as well as residences (Cheng *et al.*, 1995). Studies have focused on examining the particle size distribution and contribution of finer particles to particle load during incense burning. Increase in particle levels indoor due to incense burring has been demonstrated by Lin *et al.*

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(2002) who compared the concentrations of Total Suspended Particles (TSPM) inside and outside of a Taiwanese Temple. Particle levels inside were more than 15 times higher than outside (1316 μg m^{-3} inside vs. 73 μg m^{-3} outside). Respirable particles (RSPM: $PM_{2.5}$) forms a major part of the TSPM.

Particle ratio ($PM_{2.5}/PM_{10}$) in ambient air measured during the incense-burning period in a temple in Taiwan (Fang *et al.*, 2002) using a Micro Orifice Uniform Deposited Impactor (MOUDI) sampler averaged 69.6 ± 12.3% (ranged between 31.2% and 87.4%). High contribution of fine particles ($PM_{2.5}$) to the total concentration: average $PM_{2.5}/PM_{10}$ ratio ~82% has been recorded for two of the most famous temples in Hong Kong (Wang *et al.*, 2006). Ji *et al.* (2010) characterized the particles emitted by an incense stick in an experimental house. Near the burning incense stick, the maximum concentration was 25,500 particles cm^{-3}, while the indoor $PM_{2.5}$ concentration reached 197 μg m^{-3}. Ventilation conditions have been shown to greatly impact levels of particles and associated chemicals detected. Lung *et al.* (2003) determined the contribution of incense burning to indoor PM_{10} and particle bound PAHs under two ventilation conditions – open and closed. PM_{10} concentrations near the altar during incense burning was 723 μg m^{-3} and 178 μg m^{-3}, more than 9 and 1.6 times the background levels, under closed and ventilated conditions respectively.

It is well known that PM_{10} in typical Indian homes reach levels of 1000–2000 μg m^{-3} due to indoor activities like cooking, smoking, incense burning and combustion of other solid fuels (Smith, 1996). This is an order of magnitude higher than the levels reached in homes of developed countries i.e., < 150 μg m^{-3} (WHO, 2000) which is greater than 100 μg m^{-3} (24-hour average), the National Ambient Air Quality Standard (NAAQS) for PM_{10}in India. A recent study in northern India used Principal Component Analysis (PCA) and revealed that cooking, smoking, and incense burning are the most common sources of PAHs in indoor environments (Masih *et al.*, 2012). Roy *et al.* (2009) studied the particle size distributions (PSD) and performed chemical analysis of particles that originate from these combustion sources in Indian urban homes. Recently, emission factors of VOCs from religious and ritual activities were determined in the city of Raipur, India (Dewangan *et al.*, 2013). A follow-up to this study investigated the emission factor of PAHs emitted from different types of religious activities in India (Dewangan *et al.*, 2014). The study concluded that religious and ritual activities contribute approximately 23% of the total emission budget of total PAHs from unknown sources. The size and PAH content of temple particles have both been demonstrated to be important factors inflammation and endothelial cell response (Lin *et al.*, 2012).

This paper aims to provide an overview of the variations in particle levels, due to incense burning, inside temples of Kanpur city. Particle distribution inside temples reflects air quality and is an essential component of characterizing exposure of temple visitors to incense smoke. Particle size distribution and factors affecting observed levels have been examined. This information on exposure to incense smoke can help assess the impact of particle inhalation on the people's health in this region.

METHODOLOGY

Selection of Sampling Sites

To determine suitable sites, a survey was conducted in seven temples of Kanpur city (refer Table 1) to obtain data on building structure, ventilation conditions and number of devotees visiting the temple on a 'normal' or 'major' day. Major days fall on Tuesdays and Saturdays of each week and are considered special for the deities commonly worshipped in this region. On these days, the number of worshippers is higher in the temples and hence, there is a significant increase in burning of incense, and thus more particles are generated. Number of devotees visiting a temple has been considered as proxy for amount of incense burning in a temple. On other days of the week, the number of devotees is significantly lower, and these are regarded as 'normal' days in the study. Apart from major days in a week, it was also found from the survey that there is a significant crowd during major festivals in India, such as *Diwali*, *Holi* and *Navratri*, and these days could also be considered as major days. The survey revealed that three major types of incense are burnt in the temples of Kanpur. *Agarbatti* (incense Sticks) is a type of incense, which has a wooden core, and a thin coating of incense. *Dhoop* is a type of thick incense without the wooden core and is usually molded in a conical shape by hand. A *Diya* is an earthen lamp filled with oil or ghee (butter oil).

Since this study deals with indoor air pollution, the temples with no permanent roof, i.e., which are open to the atmosphere, were not considered. Based on the survey, three temples – Panki (PA), Kali Mathia Temple (KM) and

Table 1. Details of temples surveyed.

Temple Name	Location	Ventilation conditions of worship room	Type of Incense Burnt	Attendance on Normal Days	Attendance on Major Days
Panki (PA)	Panki	Closed	*Dhoop*	500–1000	80000–90000
Kali Mathia (KM)	Shastri Nagar	Closed	*Agarbatti*	2000–3000	5000–6000
Shani (ST)	Chunniganj	Closed	*Diya*	4000–5000	8000–9000
Tapeswari	Hamirpur Road	Open	*Dhoop*	1000	4000
Baradevi	Birhana Road	Open	*Diya*	400–500	1000–1500
Sai	Bithoor	Open	*Agarbatti*	5000	25000
Hanuman	Ashok Nagar	Open	*Diya*	400–500	2000–2500

Note: 'Open' means the prayer room does not have a permanent roof, and is open to the atmosphere.

Shani Temple (ST), where incense was burned in closed rooms, were chosen for sampling. Apart from the ventilation conditions, the three selected temples also differed in the major type of incense used (refer Table 1). *Dhoop* was majorly used in PA, *Agarbatti* in KM and *Diya* in ST. Attendance on normal days was found to be lowest at PA (500-1000). Although the number of devotees visiting the temple on a major day almost doubled for KM and ST, it jumped up ~80 times for PA and was more than an order of magnitude higher than at the other two temples.PA is isolated from traffic compared to the other two; the nearest road being 100 m from the worship room, as compared to 10 m for KM and 20 m for ST. Detailed information on the structure and layout of temples selected as sampling sites can be found in the Supplemental Information (SI)

Air Sample Collection Procedure

Particle Sample Collection

Active air sampling was conducted inside the temple near the worshipping area or altar, of each temple using Micro-Orifice Uniform Deposition Impactor (MOUDI™, Model 110, MSP Corporation) for size segregated particle samples. An Optical Particle Counter (OPC 1.108 NR, GRIMM Aerosol) was also run concurrently with MOUDI for a short time to get an estimate of particle count. MOUDI is a cascade impactor intended for general-purpose aerosol sampling and consists of several stages. At each stage, jets of particles laden air impinge upon an impaction plate, and particles larger than the cut off size of this stage cross the air streamlines and are collected upon the impaction plate. The six stage MOUDI includes cut off points of 10, 3.2, 1.0, 0.32, 0.1, and 0.056 μm. Aluminum filters with 47 mm diameter were used to collect particles. Instrument flow rate was adjusted to 30 L min^{-1} as per the manufacturer's recommendation. The OPC measures real-time size distribution of particles at sample resolution of 1 minute. Real-time measurements were carried out in number mode (counts per liter) at a flow rate of 1.2 L min^{-1}.

Sampling Schedule

Active air sampling period covered the pre-winter (November and early December 2013) and winter season (January and early February 2014) in Kanpur, India (refer Table 2). Nine sets of samples collected from the 3 temples (5 from PA, and 2 each from KM and ST) include two sets of samples collected at PA and ST in one day. PA and KM were sampled on both 'major' and 'normal' days. ST was sampled on major days only. Other than for sample ST1 (refer Table 2), sampling duration with MOUDI was at least four hours. The OPC measures particles sizes above 0.3 μm and has a count range of 1 to 2,000,000 #/L. During the initial test runs in the temples, the values reported for particle levels were well above the designated count range. To avoid any damage to the instrument such as clogging due to high number concentration of particles, the OPC was run for a reduced time (sampling schedule is given in Table S1 (SI). It may be recalled here that even slight movement near the OPC causes significant deviation of the measurement. Hence, the instrument was set up just above the incense burning location at a height of 10 feet above ground to minimize disturbances.

Data Analysis

Filters from MOUDI were pre - and post- weighed to obtain size segregated particle size distribution for each sample. This data was further analyzed to obtain mass median aerodynamic diameter (MMAD) and geometric standard deviation (GSD) as described below. The MMAD and GSD are the two main features of particles size distribution used to describe the properties of particles at particular microenvironment. MMAD means the particle diameter below and above which 50% of the mass concentration of particles exist. GSD, dependent on MMAD, describes nature of particle distribution. If GSD ≤ 1.25 than it implies monodisperse particle and if GSD > 1.25 then it implies poly-disperse particles. These are calculated by using lognormal distribution concept. The mathematical expressions are as:

$$MMAD = \sqrt[N]{\prod_{i=1}^{n} D_i^{(n_i)}} \quad (1)$$

$$\log GSD = [\frac{\sum n_i (\log D_i / MMAD)^2}{N-1}]^{1/2} \quad (2)$$

where,

D_i = midpoint particle size;

n_i = mass of particles in group 'i' having midpoint of size D_i;

N = total mass concentrations, summed over all intervals.

Table 2. Sampling schedule in temples.

Code	Date	Season	Day	Time	Temp. (°C)	Most abundant particle range (nm)	MMAD (μm)	GSD (μm)
PA1	3 Dec 2013	Pre- winter	Major	5 AM–9 AM	21	40–70	0.44	4.22
PA2	3 Dec 2013	Pre- winter	Major	4 PM–8 PM	26	40–70	0.42	3.84
PA 3	28 Jan 2014	Winter	Major	7 AM–11 AM	19	70–150	0.40	3.18
PA 4	28 Jan 2014	Winter	Major	5 PM–9 PM	24	70–150	0.54	3.33
PA 5	29 Jan 2014	Winter	Normal	6.15 AM–0.15 AM	16	40–70	0.51	6.91
KM 1	30 Nov 2013	Pre- Winter	Major	7.15 AM–11.45 AM	18	40–2000	1.10	7.56
KM 2	31 Jan 2014	Winter	Normal	6.15 AM–10.15 AM	14	70–150	1.03	8.57
ST 1	1 Feb 2014	Winter	Major	10.30 AM–1.00 PM	16	40–200	0.84	19.91
ST 2	1 Feb 2014	Winter	Major	3.45 PM–8.45 PM	18	80–200	0.76	9.97

RESULTS AND DISCUSSION

Particle Mass

The total particle mass from MOUDI represents PM_{10} measured indoors. Other than PA, total particle levels in temples even on *major days* (KM1, ST1, and ST2) were all within 3 mg. The two normal days in the two different temples (PA5 and KM2) were similar (< 2.8 mg). These values were converted to PM_{10} concentration and results are presented in Table 3.

According to WHO guidelines on indoor air quality (WHO, 2006), the 24-hour mean PM_{10} concentration should be less than 50 μg m^{-3}. The national ambient air quality standards (NAAQS) for India allow 24- hour mean PM_{10} concentration up to 100 μg m^{-3}. Though both of these limits are for ambient air, same guidelines were recommended for assessment of indoor air quality in terms of PM_{10} and $PM_{2.5}$ (WHO 2006). Applying this criteria, it is seen that in all cases, the particulate concentration inside the temple is significantly higher than permissible limits (2 to 20 times higher than NAAQS and 4 to 40 times the WHO guidelines). Some of the concentrations found in the present study are higher than the reported values inside temples in Taiwan (mean of 1316 μg m^{-3} inside the temple) and Hong Kong (mean of 1500 μg m^{-3} during peak hours). Large discrepancy between the number of worshippers at Panki temple on normal days and major days (Table 1) accounts for low mass concentration on a normal day, PA 5 as compared to the other samples, all collected on major days.

Particle Size Distributions (Mass)

Nature of Particle Size Distribution

Particle mass was collected in size bins ranging from 18–0.056 μm. Particles occur in all three modes (refer Fig. S2, SI): nucleation (Aitken) mode (particle diameter, dp < 0.1 μm), accumulation mode (particle diameter: 0.1 μm > dp > 1 μm), and coarse mode (particle diameter dp > 1 μm).

GSD values for all samples are greater than 1.25 (refer Table 2), which characterizes poly-disperse particle size distribution. The values for MMAD which means the particle diameter below and above which 50% of the mass concentration of particles exist, varied from 0.40 to 1.1 μm i.e., majority of particles occur in the accumulation mode (particle diameter: 0.1 μm > dp > 1 μm). The high range for GSD values (3.1–19.9), representing presence of particles in a variety of sizes, combined with majority of particles detected being in accumulation mode suggests significant role played by coagulation in these microenvironments. As noted by Chuang *et al.* (2013) coagulation could be a vital process for the growth of primary incense combustion particles through the intermixing with volatile organics.

Most Abundant Particle Size Range

In samples from ST (both major days) and KM (major and normal days), particles in the size range 40–200 nm show marked abundance. Contrast in particle size distribution based on particle density is suggested by data from KM. On a normal day sample, KM2, most of the particles are in the size range < 0.1 μm. For KM1 (major day), most abundant particle (40–500 nm = 0.04–0.5 μm) closely followed by particles in size range 500 – 2000 nm (0.5–2 μm) include all three modes but is dominated by particles in accumulation mode (d_p: 0.1 μm > d > 1 μm) and coarse mode (d_p > 1 μm). At PA, particles were abundant in the nucleation mode (ultrafine size range of 40–70 nm in PA1, PA2, and PA5) while samples from major days at PA (PA3, and PA4) show abundance of particles on the borderline; more towards the accumulation mode (70–150 nm).

MMAD values lie in the range 0.402 μm to 1.09 μm which in all cases, other than KM1, lie outside the particle size range that is highly abundant. This again suggests that particle accumulation process is quite active and plays an important role in particle size distribution captured in the temple microenvironment. It is seen that particles in accumulation mode contribute maximum to total particle load by mass. Particles in accumulation mode show maximum contribution to total particle mass at PA (73–90%) followed by ST (61–64%) and KM (56–58%). A closer examination of the data reveals influences of ventilation conditions, time of sample collection and amount of incense burned on particle distribution. This is discussed in a later section.

Seasonal Variation in Stage Wise Distribution of Particles

It is seen that particles in accumulation mode are most abundant. Stage wise distribution of particle mass collected by MOUDI (refer Figs. 1 and 2) reveals that the major contribution by mass came from particle size ranging between 0.1–0.32 μm. This was followed by the next higher particle size bin of 0.32–1 μm in all the winter samples (PA3, PA4, KM2, ST1, ST2), and lower particle size bin of 0.056–0.1 μm in all pre-winter samples (PA1, PA2, KM1). Dominance of higher particle size in winter and vice versa for pre-winter suggest that a greater degree of coagulation occurs in the winter season as compared to the pre-winter season, leading to more particle collection in the S5 (0.32–1 μm) filter. *It must be noted that the Y-axis scale for PA (refer Fig. 1) is an order of magnitude higher than for KM and ST (refer Fig. 2).*

Particle Number Concentration (OPC)

As mentioned earlier, based on the high particle concentrations detected at the temples, OPC was run for a short time interval (Table S1) and was set up just above the incense burning location at a height of 10 feet above ground to minimize disturbances. OPC measures count of particles > 0.3 μm and hence the values obtained cannot be regarded as total particle count. Results from OPC provide a preliminary idea about average particle counts and distribution on a size segregated basis.

Table 3. Particle Mass Concentration in temples.

SET	PA1	PA2	PA3	PA4	PA5	KM1	KM2	ST1	ST2
Conc. (μg m^{-3})	2152	2184	2058	1993	286	316	187	262	230

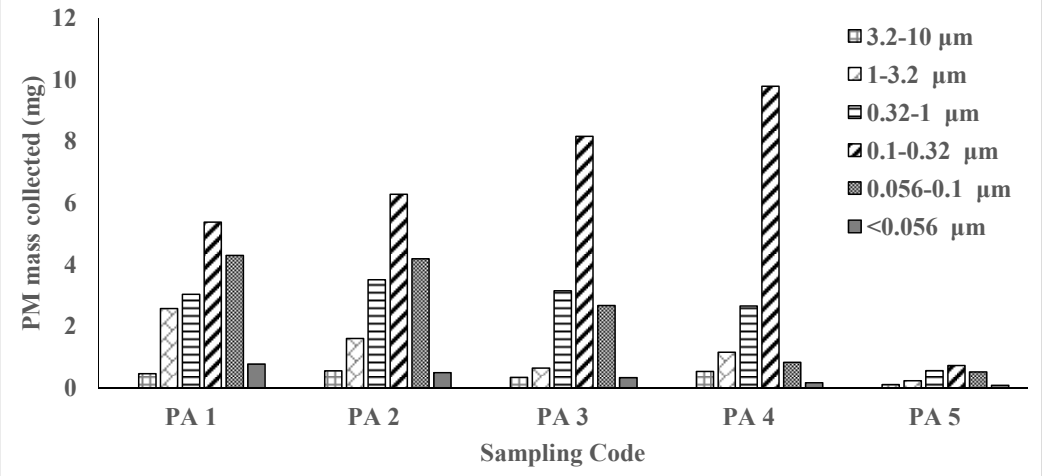

Fig. 1. Mass of particle collected in PA for all stages of MOUDI.

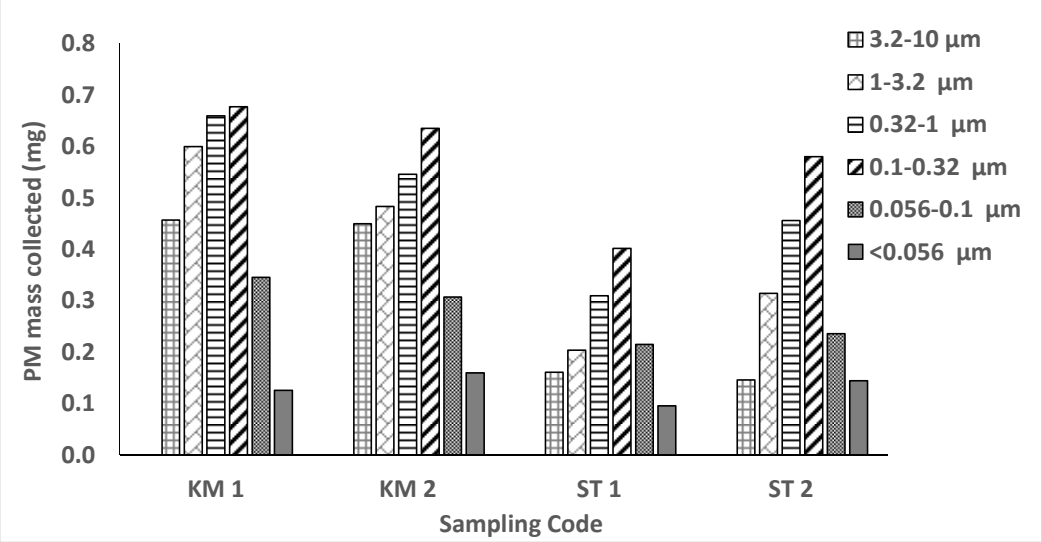

Fig. 2. Mass of particles collected at KM and ST for all stages of MOUDI.

Average Particle Concentrations Observed

Average of recorded values presented in Fig. S3 (SI) reveal very high values of particle number concentration (> 10^6 #/L). Error bars on the graph depict standard deviation. Levels were well above the concentration limit of the OPC (except for KM 2). Highest levels were recorded at PA.

Particle Count on a Size Segregated Basis

For all the sets, a consistent trend - drop in number concentration with increasing particle size - was observed. $PM_{2.5}$ constituted over 99.9% of the particle load measured while PM_1 was almost 99% of the particle load. The PM_1 contribution is likely to be an underestimate given that the OPC records particle size > 0.3 µm. For ST and KM, smaller size particles contribute most significantly to the particle load. In contrast, at PA, contribution of larger particle sizes is also seen. Particle counts at ST, in general, were higher than those noted at KM (refer Fig. A1). This is in contrast to particle mass recorded by the MOUDI where levels at ST are lowest recorded. The finer particles, lighter in weight, contribute significantly to the particle count at ST, and result in lower mass. This can be attributed to good ventilation conditions in the temple, which limits particle coagulation.

Contribution of Respirable (RSPM) and Fine Particles to Total Particle Mass and Particle Count Measured

Table 4 shows the percentage contributed by Respirable ($PM_{2.5}$) and fine (PM_1) to the total particle load for all sets. Data from MOUDI has been used for contribution in mass and from OPC for count. In terms of particle count (OPC data), greater than 99% of the particles are respirable ($PM_{2.5}$) while in terms of mass, contribution of $PM_{2.5}$ is lower, and comprised 75–95% of particle load.

Similarly, finer particles (PM_1) contribute less (80–92%) of particle mass and more of particle count (96–99%) at PA. Mass contribution range is slightly lower at the other two temples (60–70%) while the contribution to count is higher (minimum 99%). This clearly shows that PM_1 are emitted in very large numbers but contribute lesser in terms of mass. Contribution of PM_1 to particle count is likely to be higher

Table 4. Contribution of $PM_{2.5}$ and PM_1 top article loads obtained by MOUDI and OPC.

Set	Mass - MOUDI (size bin: 0.1 μm to 10 μm)		Count - OPC (size bin: 0.3 μm to 20 μm)	
	Contribution of $PM_{2.5}$	Contribution of PM_1	Contribution of particle$_{2.5}$	Contribution of PM_1
PA 1	92.75	80.71	99.90	99.33
PA 2	93.51	86.06	NA	NA
PA 3	95.28	92.07	99.82	96.45
PA 4	91.79	86.02	99.89	97.52
PA 5	90.05	82.29	99.97	99.75
KM 1	75.34	59.83	99.93	99.67
KM 2	74.72	60.79	99.82	99.39
ST 1	78.26	67.71	99.97	99.84
ST 2	82.98	70.71	99.98	99.88

than recorded given that the OPC records particle size > 0.3 μm. Particles in this size bin being very light will not make much difference to contribution in the mass mode.

These observations, emissions of finer particles in large numbers from incense burning inside temples, highlight need for investigation of chemical composition of these particles followed by evaluation of their associated health impacts.

Influence of Ventilation Conditions, Amount of Incense Burnt and Sample Collection Time on Particle Levels Observed

Influence of number of incense sticks burned and ventilation conditions, which seem to be the primary factors controlling particle number and size detected in the temple microenvironment, along with time of sample collection are discussed below.

Ventilation Conditions

The temple that displayed the lowest particle mass on major days was ST (refer Table 3). Even though sampling time for ST2, collected in evening, was double that for ST1, collected in morning (5 hours vs. 2.5 hours) the difference in particle mass collected was lower than expected (ST 1: 1.51 mg and ST 2: 2.00 mg). Also to note is the fact that number of visitors in ST on a major day (ST1, ST2) are ~three times that in KM on a normal day (KM2) (refer Table 1). Still the levels of particles from ST are slightly lower than that on a normal day at KM (KM2) (refer Fig. 2). The comparatively low values for ST can be attributed to the good ventilation conditions in the temple. There are walls only on three sides surrounding the temple (Fig. S1d), hence most of the particle generated could escape and not be detected by the instruments. In addition, the temple was well equipped with a number of large exhaust fans just above the platform where incense burning took place. The temple was well managed and cleaning was performed twice a day. All these factors contributed to low particle collection by the MOUDI at ST.

In contrast, particles in PA appear to get a longer residence time during the winter season, which suggests poor ventilation conditions in the temple. This is demonstrated by lower particle size range contributing more to particle mass load in pre-winter vs. higher range in winter time (refer Fig. 1) as discussed earlier.

Major vs. Minor Day (In Terms of Particle Count)
Amount of Incense Burnt

It was observed that the *particle count* for the slightly coarser bin of 0.4 to 0.5 μm was significantly higher on major days (PA1–PA4 and KM1) than the respective minor days (PA5 and KM2). Thus, coarser size particles (in this case, particles ranging from 0.4 to 0.5 μm) occur in higher concentration on major days. A possible reason could be that a large number of fines were being generated on major days, which then coagulate to form coarser particle. Dominance of finer particles at ST, the temple with best ventilation conditions can also be attributed to the low retention time for particles resulting in lesser coagulation.

Sample Collection Time

Samples collected in the morning on a normal day show abundance of smaller particles (both at KM2, and PA5) in the nucleation mode (< 0.1 μm). Just as for particle mass, particle count in PA was the highest compared to the other temples. The sampling for PA1 was started on 6.53 AM. At this time, the crowd was relatively sparse, lesser incense burning per unit time which resulted in slightly lower levels of particles generated. During the sampling of PA3 (8.57 AM) and PA4 (7.30 AM), the crowd was noticeably larger, which led to higher readings by the OPC. The particles size that show greater abundance also start at a higher level on these two dates (70 nm vs. 40 nm, Refer Table 2).

CONCLUSIONS

Particle mass concentration values recorded in three temples studied in Kanpur city, where incense burning occurs within closed rooms, exceed the 24-h average National Ambient Air Quality Standard (NAAQS, India) of 100 μg m^{-3} for PM_{10} and are much higher than studies performed elsewhere. In general, compared to a 'normal' day, particle levels were higher on a 'major' day, when the number of people visiting a temple is larger resulting in larger amount of incense burning. PM_{10} mass concentration reached up to 2336 μg m^{-3} inside the temple at Panki (PA), which has the largest number of devotees visiting every day. Fine particles (PM_1) account for > 98.9% of total particle load on count basis. Average $PM_{2.5}$contribution to particle load (PM_{10}) ranged from 75–92% in terms of mass and an average of 99.9% in terms of particle count. Particles are polydispersed

and primarily occur in accumulation mode. Coagulation mechanism, more dominant in winter time, is a significant contributor in particle distribution. Ventilation conditions, along with seasonal variation in residence time appear to be major factors influencing particle size distribution observed. These results clearly support the need to set up Indian indoor air quality standards and may provide useful information for setting up the same.

ACKNOWLEDGEMENTS

The support extended by temple authorities in conducting the survey and later in sample collection is sincerely appreciated. Support extended by Ms. Deepchandra Srivastava, and Mr. Om Prakash Choudhary in sample collection and analysis was helpful. The authors would also like to thank Dr. Arthur Frank, Drexel University, for his constructive comments on the manuscript.

SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at http://www.aaqr.org.

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Received for review, May 10, 2016
Revised, October 24, 2016
Accepted, November 14, 2016

Supplementary Information

S1. Details of Temples surveyed as possible sampling sites

Kali Mathia (KM) Temple

KM consists of an entrance from the front, which leads directly to the shrine, where the incense is burnt. There are 2 exits located at either side of the building (refer Figure A1b). Apart from the shrine, incense is also burnt outdoors on stands, as marked in red in Figure A1b(refer Figure A1b). The shrine is located at the center of the building. The ritual consists of burning incense and taking a clockwise path around the shrine. The interior consists of large open windows with grids and openings for ventilation above the windows. There are 10 ceiling fans and 6 exhaust fans (not shown) – 4 located at the back wall and 1 each on the side.

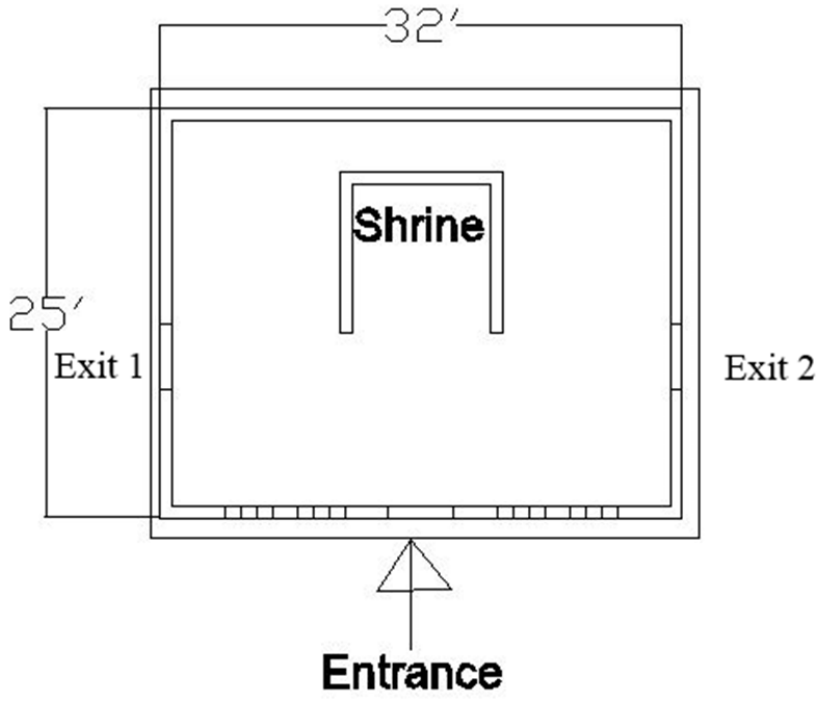

Figure S1a: Schematic of Kali Mathia Temple

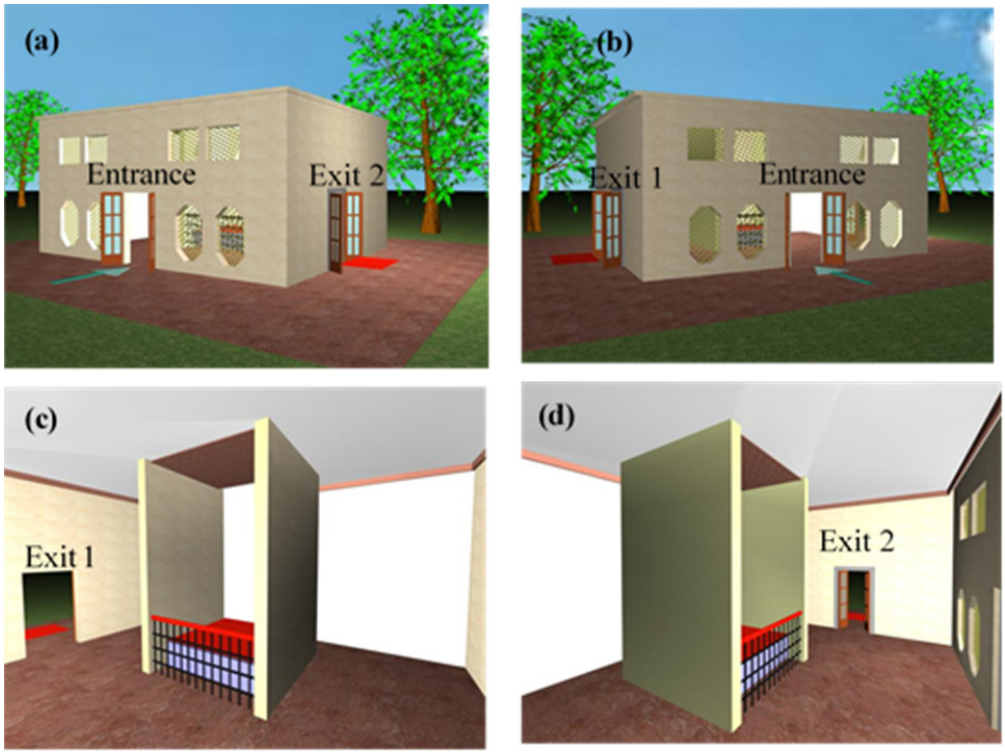

Figure S1b: Layout of Kali Mathia Temple (a) and (b) Outside View (c) and (d) Indoor view

Shani Temple (ST)

ST layout consists of a common entrance and exit as shown in the Figure A1c(refer Figure A1c). The door opposite to the entrance is kept closed at all times. The temple is open to the atmosphere on one side. The interior consists of 6 exhaust fans as shown in the Figure. Two big trees are present in the interior of the temple beside the shrine, with the trunks going through the ceiling. The shrine is located in the center of the building, in front of which worshippers form a line, after which they burn *Diyas*under the trees (marked in red).

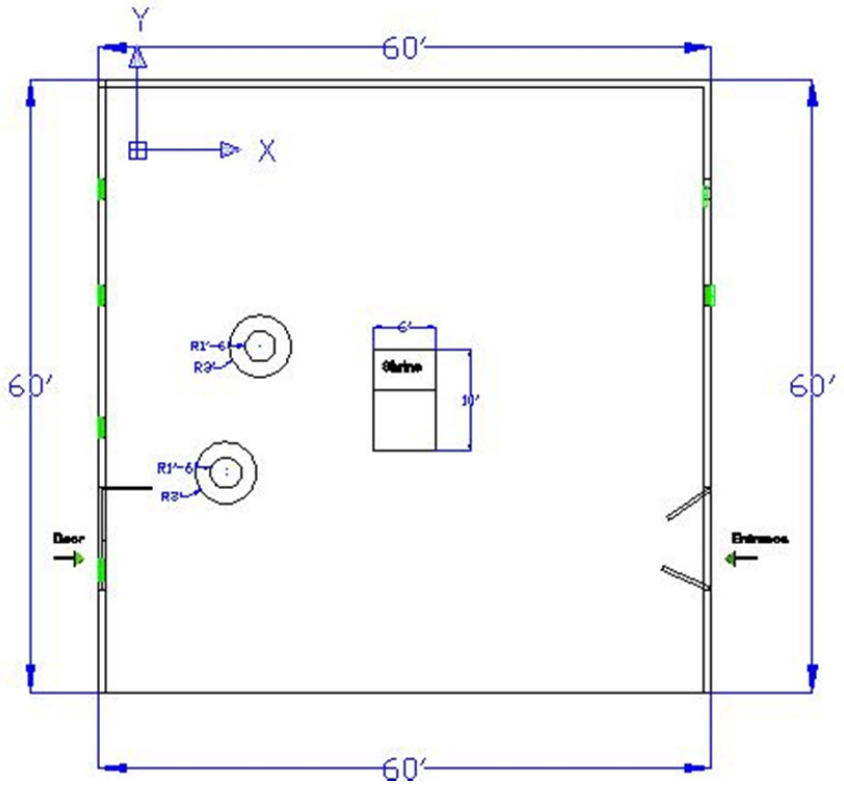

Figure S1c: Schematic of Shani Temple

Figure S1d: 3D Layout of Shani Temple

Figure S1e: Outdoor image of Panki Temple

S2. Pre sampling preparation

Substrates were placed in an oven at 180°C for four hours to remove moisture and any volatile compounds. They were then kept in cases and conditioned in a desiccator for 24 hours. Each substrate was then labeled and weighed 3 times using a microbalance (METTLER MT5 Analytical Microbalance)before sampling. Upon completion of the sampling, the substrates were again conditioned in the desiccator for 24 hours and were weighed. Particle mass collected in each stage was determined by taking the difference of the two readings.

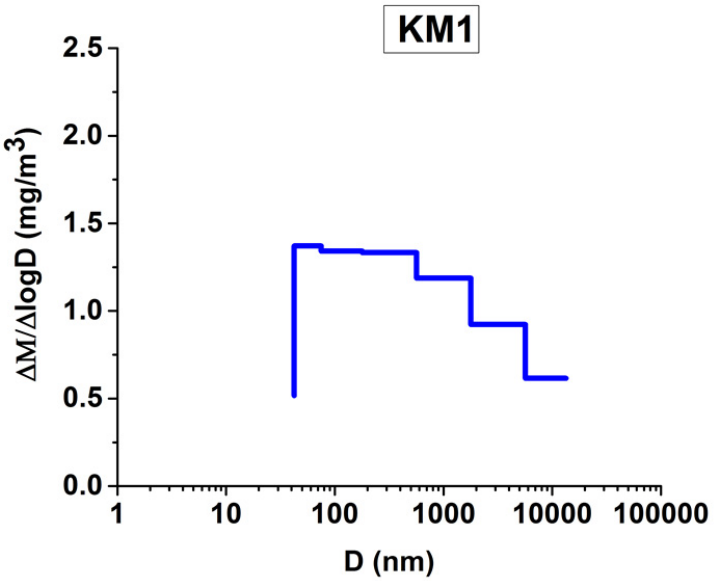

Figure S2a

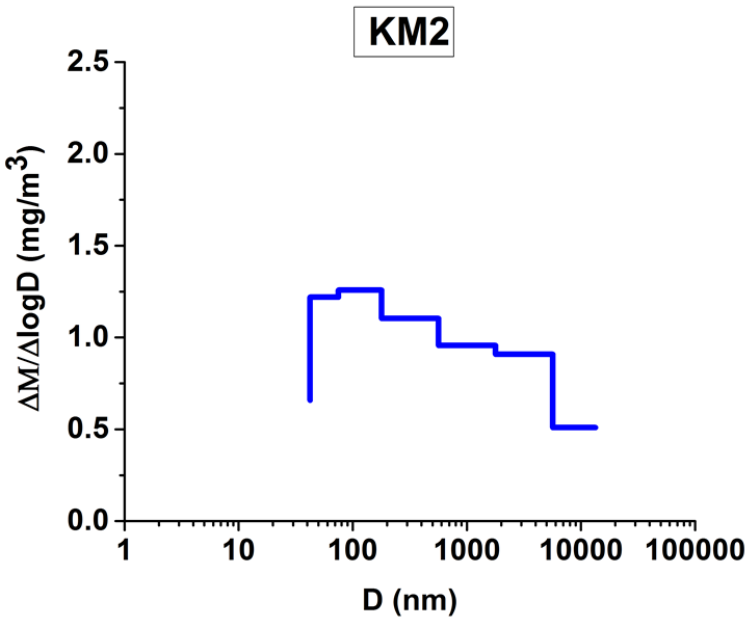

Figure S2b

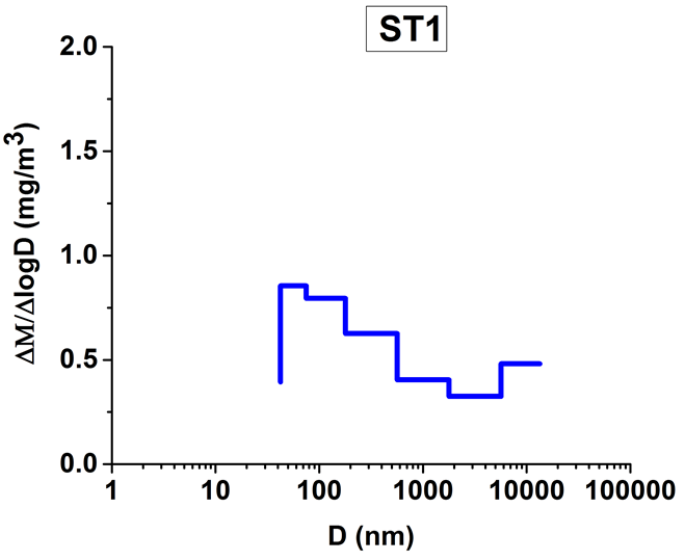

Figure S2c

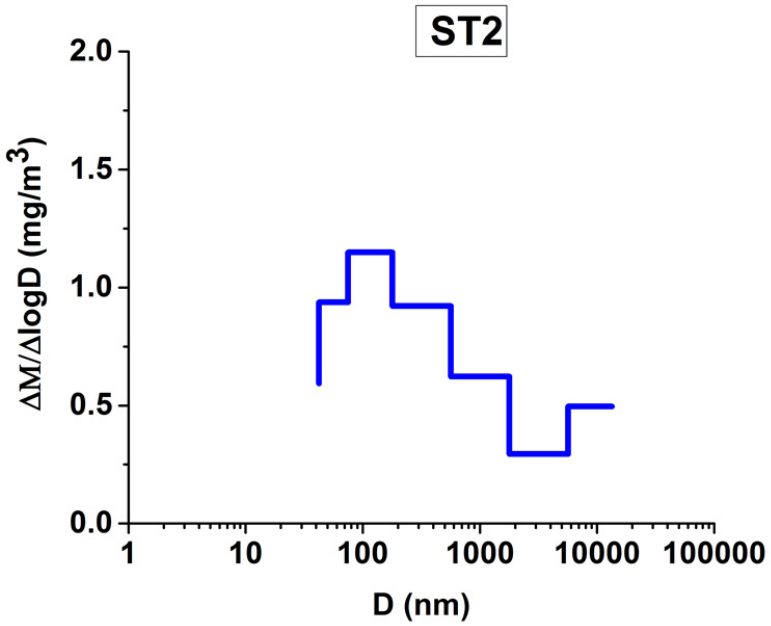

Figure S2d

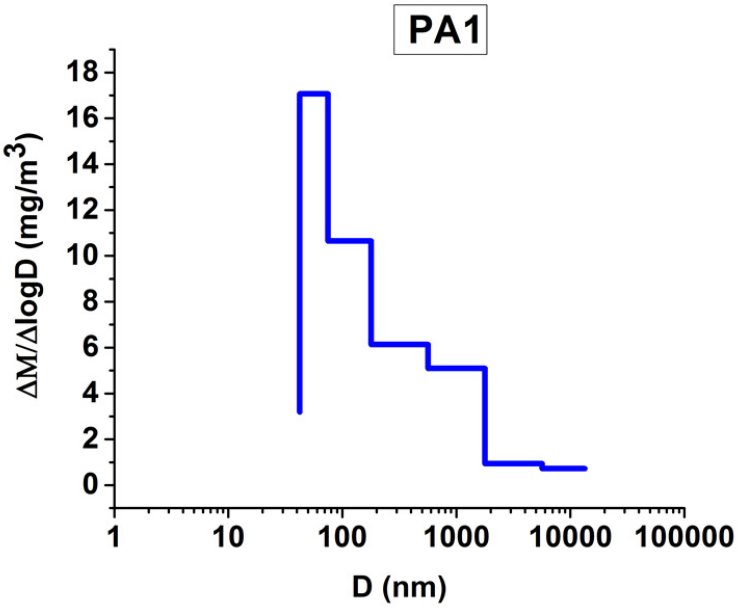

Figure S2e

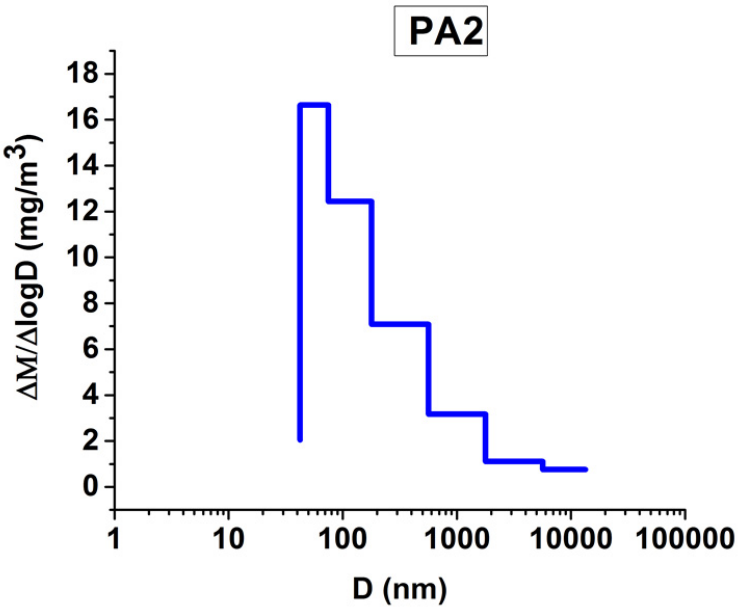

Figure S2f

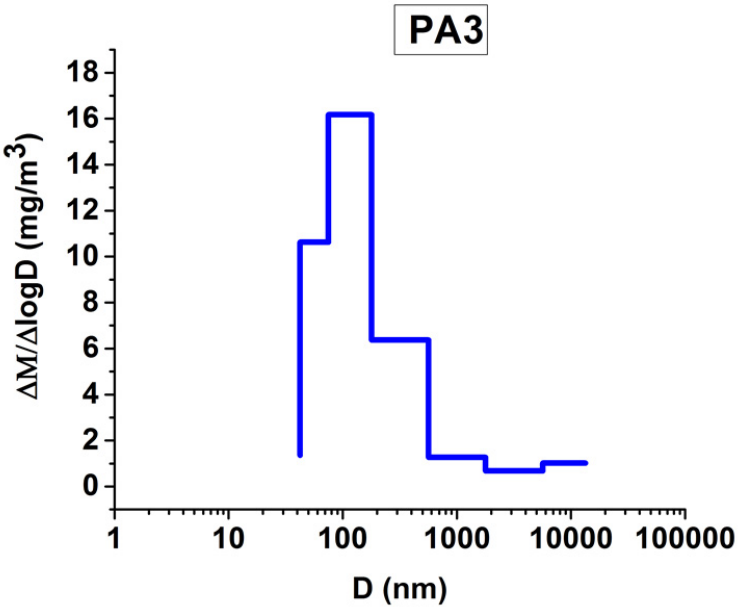
PA3
ΔM/ΔlogD (mg/m3)
18
16
14
12
10
8
6
4
2
0
1
10
100
1000
10000
100000
D (nm)

Figure S2g

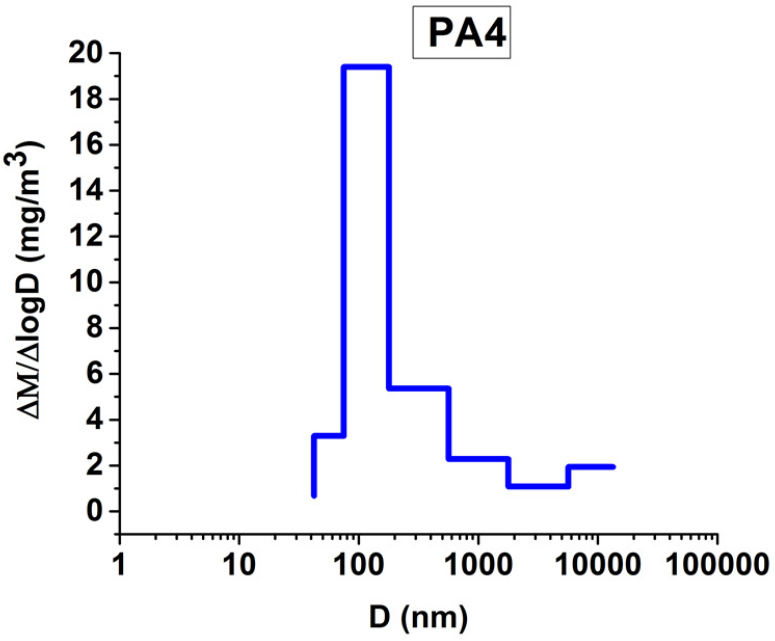
PA4
ΔM/ΔlogD (mg/m3)
20
18
16
14
12
10
8
6
4
2
0
1
10
100
1000
10000
100000
D (nm)

Figure S2h

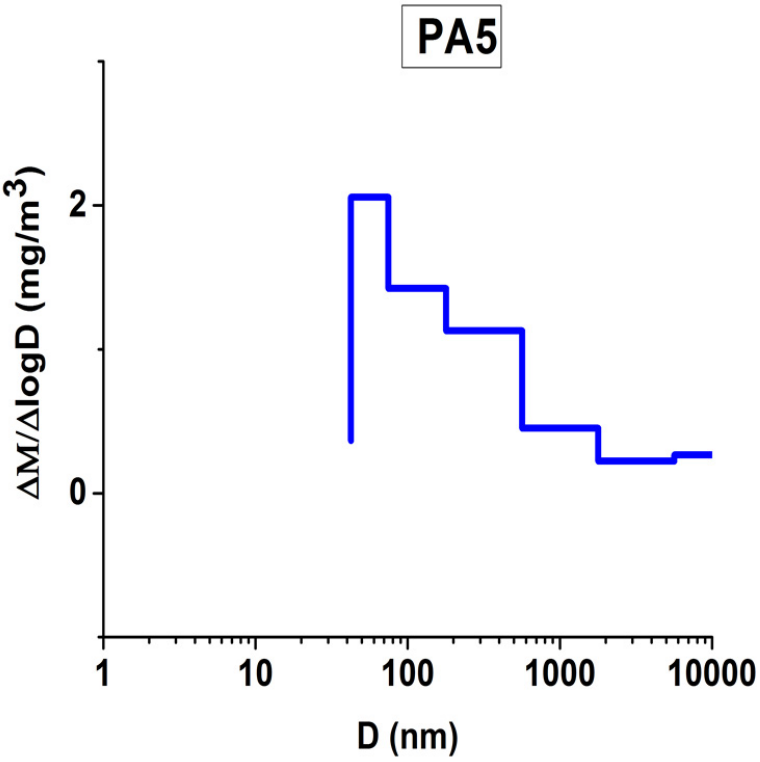

Figure S2i

Figure S2 Total particle mass-size distribution for all samples

Table S1

Table 4. Sampling schedule for OPC in temples

Sampling Code	Time	Sampling Duration (min)
PA 1	4.51 AM	45
PA 2*	NOT USED	-
PA 3	8.57 AM	45
PA 4	7.30 PM	45
PA 5	9.10 AM	45
KM 1	6.53 AM	120
KM 2	7.23 AM	120
ST 1	12.18 PM	45
ST 2	6.43 PM	45

* OPC experienced clogging during the PA 1 sampling, and as a result, sampling for PA 2 set, later the same day as PA1, could not be conducted.

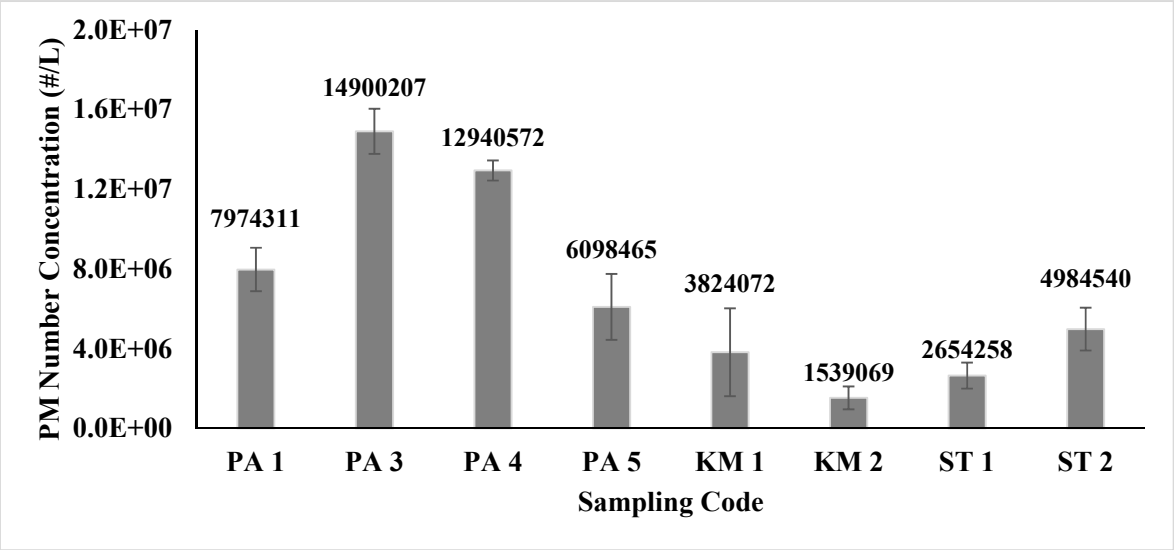

Figure S3 Average particle number concentration measured by the OPC in temples