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Dispersion and Personal Reception of Particulate Matter Generated by Burning Incense

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Abstract

This study investigates particulate matter dispersion and heat index during incense burning in ventilated and unventilated rooms. Two room sizes were examined, utilizing common incense and a smokeless version. Personal receptions for TPM were measured using a personal air sampler and particulate matter dispersion using an AEROCET model 531S, while the heat index was monitored with a heat stress monitor. Results indicate that all room conditions adhered to Department of Health criteria for total particulate matter (TPM). Person-based exposure in unventilated rooms was higher than in ventilated ones. Incense burning alone did not significantly impact a 50 m space based on heat index measurements. Additionally, individuals exposed to high total airborne matter (TAM) concentrations were likely to encounter elevated levels of PM_{10} and $PM_{2.5}$. The concentrations of TPM, PM_{10} and $PM_{2.5}$ from incense burning exhibited strong correlations, suggesting that any one measurement could reasonably predict the other two.

Introduction

Ambient air quality is a metric representing the level of impurities in the ambient air that may harm human health and other living beings or impacts on human property and the surrounding environment, depending on the amount of contaminant and exposure time. If the contaminant content is lower than the level that causes such problems, the air quality is considered to be at an appropriate level without acute health hazards. But if the amount of contaminants is higher than the acceptable threshold for the body, it will affect the respiratory system and heart rate (Andersen et al., 2008; Anderson et al., 2012; Escamilla-Nuñez et al., 2008; Gruzieva et al., 2013; Schultz et al., 2012; Tsou et al., 2021; WHO, 2021). Indoor air quality problems affect

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the health of users of the building, both in the short term, that leads to acute illnesses and in the long-term, with toxicity caused by accumulation in the body and subsequent organ damage, caused by accumulation of carbonaceous aerosols, carbon monoxide (CO), nitrogen oxides and inorganic ions (Bootdee et al., 2016; Davison et al., 2021; Karner et al., 2010; Peachey et al., 2009). Dust is a pollutant commonly found on the road (Gehring et al., 2006; Gordian et al., 2006; Hoffmann et al., 2006; Kim et al., 2008; Morgenstern et al., 2007; 2008) and contains both organic and inorganic components. Large dust particles, with diameters ≥ 1 µm, are readily seen. Particles with diameters >10 m tend to fall with gravity and accumulate on the ground, leading to, for example, dirty floors, which feel uncomfortable when walked on and visible furniture dust marks (Hien et al., 2022). Smaller particles, <10 µm in diameter, tend to enter the lungs and accumulate inside the human body. Very small particles, <2.5 µm, will enter the lungs deeper, entering the lower respiratory tract and clinging to or even breaking up in various organs. Large amounts, ingested over time, can cause fibrosis or lesions in the lung tissue and deteriorate lung function, causing asthma or emphysema. On the other hand, dust accumulated in the bronchial tubes can lead to bronchitis and other respiratory diseases (Chen et al., 2021; Kumar et al., 2014). Incense is used, following ancient beliefs that still persist in ASEAN countries (Hien et al., 2022); it is found in temples and shrines, but also in homes (Department of Industrial Promotion, 2000). Incense usually burns with incomplete combustion, thus burning incense can add various pollutants to the surrounding air. Incense sticks contain glue, perfume and various synthetic colors, including resins, aromatic wood, bark, herbs, flowers, essential oils and synthetic substitute chemicals used in the perfume industry (Jetter et al., 2002). The pollutants of incense include small dust particles, carbon dioxide, carbon monoxide, nitrogen oxides, methane and carcinogens as well as heavy metals, that spread in the air in the area where incense was burned. These pollutants can affect both the environment and the health of people who inhale the fumes/dust particles. However, the severity of symptoms will depend on the amount and duration of exposure, including individual characteristics. The risk group consists of young children, elderly, pregnant women, people with congenital diseases, including patients with cardiovascular, respiratory disease and other chronic diseases, all of whom will be affected more severely than the general public (Nakrob et al., 2015).

Incense is burned in a wide variety of locations – ranging from wide open spaces located outside large temples to large internal halls, spaces that may be constricted by extensive collections of religious artefacts, which may have accumulated over centuries as well as to small shrines in small poorly ventilated rooms inside private houses. Previous work identified a wide range of pollutants from burnt incense (Lin et al., 2007; Silva et al., 2021; Hien et al., 2022). It is important to understand how burning incense affects the inhabitants of various spaces and the heat generated in these spaces in order to assess related health effects.

This study can be used as basic information for surveillance and avoidance of serious hazards to health and the environment caused by dust from burning incense inside buildings (Department of Health, 2016).

Materials and methods

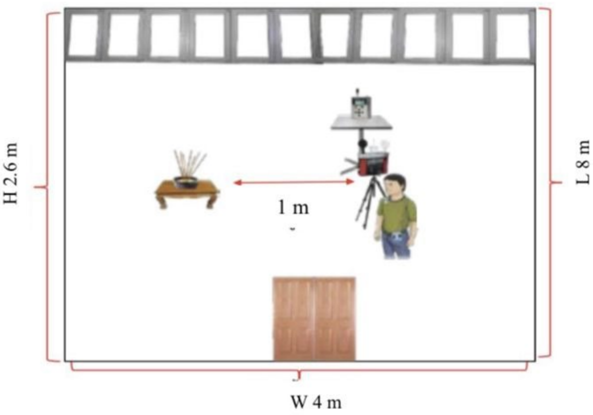
1. Study area

We measured particulate matter (TPM, PM_{10}, $PM_{2.5}$) concentrations experienced by individuals from incense burning in ventilated and unventilated rooms. Fig. 1, we used two rooms in the Department of Environmental Sciences, Faculty of Science and Technology, Rajabhat Maha Sarakham University: one room was a small 4x8x2.6 m^3 and one room was larger at 8x8x2.6 m^3, furnished with various windows and doors - see Table 1,

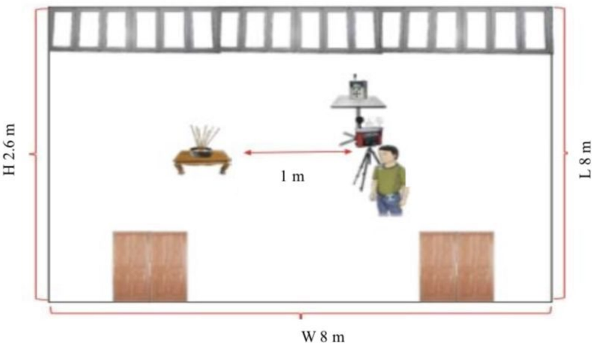
Table 1 Details of small and large rooms used in the study

Rooms	Size (WxLxH) m^3	Windows		Doors		Location
		Size (WxH) m^3	set	Size (WxH) m^3	set	
Small	4x8x2.6	0.6x1.1	9	0.16x0.2	1	16.19671°N, 103.27675°E Building 9, RMU Univ.
Large	8x8x2.6	0.6x1.1	18	0.16x0.2	2	

where 'set' indicates the numbers of windows and doors. Rooms were set as 'ventilated' by opening all doors and windows and 'unventilated' by closing all doors and windows.



(a) Small room diagram



(b) Large room diagram

Fig.1 Room layout and sizes

2. Types of incense sticks and quantities used in the study

The incense used in the study was divided into two types: common incense stick and a smokeless incense : dimensions, mass and burning time are shown in Table 2. During the experiment, a single pack of incense (45 sticks) was burnt in all conditions.

Table 2 Types of incense sticks and quantities used

Type	Length (mm)		Diam (mm)	Mass (mg)			Time (min)	Pack size	Manufacturer Source
	Tot	Inc	Inc	Stem	Inc	Res			
Common	326	225	3	590	990	131	56	45	Jimboon ChiangMai
Smokeless	326	225	3	579	960	125	48	45	Fresh market, Maha Sarakham Province

Remark: Inc = incense (dimensions and mass of active part)
Stem = bamboo stem
Res = residue, mass of stick after burning
Time = Time for incense part to burn

3. Study parameters

3.1 Size of dust

The amount of dust dispersed in the air from incense burning inside a room, with and without ventilation, was measured for dust of different diameters:

- Total Particulate Matter (TPM) < 100 µm
- Particulate Matter < 10 µm (PM_{10})
- Particulate Matter < 2.5 µm ($PM_{2.5}$)

3.2 Period of study

The amount of dust dispersed in the air was recorded every 10 min for 8 hr.

3.3 Ambient conditions

The measurements were taken during Thailand's rainy season, when external temperatures were typically 30-34°C, with high humidity (90% RH) but negligible wind speeds. Inside, temperatures ranged from small room: 19.2-22.0°C; large room 20.6-22.4°C

4. Dust measurement tools and locations

Sampling devices were installed at 1 m from the table on which the burning incense was placed.

4.1 Dust sampling tool (TPM, PM_{10}, $PM_{2.5}$ in the air

Dust and particulate matter were measured with an AEROCET model 531S (Met One Instruments, Inc., Oregon, U.S.) set in mass mode. Before every use, the battery was fully charged and the system calibrated using the Zero Count Filter.

4.2 Particulate matter meter (TPM at person received)

A personal air sampling pump, Gil Air Plus (Shawcity Ltd., Oxfordshire, U.K.) was installed at chest level on the mannequin, set flow rate pump 2,000 cc/min and set 1 m from the incense burning table. Before using the tool, the glass 37 mm fiber filter paper was dried in a desiccator for 24 hr. The filter paper was weighed before and after use.

4.3 Heat index measurement

We used a heat stress monitor, 3M Questemp 32 meter (Wet Bulb Globe Temperature - WBGT - Index ISO 72437), It was calibrated every time before use. It was installed on a stand level of the mannequin's chest and placed in an area where air could pass freely. It was installed at least 25 min before use to ensure it was warmed up and stable. WBGT values were recorded every 10 min.

5. Experimental procedure

The laboratory was an open space with a 350 mm high table for incense burning in the center. The measurement tools were installed 1 m from the incense burner, see Fig. 1. The measurement tools used were dust meter and particle meter (AEROCET brand, model 531S), Gil Air Plus personal air sampling pump) and heat stress monitors. After turning on all monitors, we burnt incense and collected data for 8 hr. Samples were collected under all conditions: small vs large room, non-ventilated vs ventilated room and general vs smokeless incense.

5.1 Data analysis

The amount of dust of all sizes collected was analyzed to measure the difference in the amount of dust between ventilated and non-ventilated rooms by paired samples t-test (95% confidence level) and the total amount of particulate matter received by a person, calculated from the mass of filter paper before and after sampling with the personal air sampling pump, Gil Air Plus brand, calculated following Wipada & Navapol (2016):

$$W = (W_f - W_i) \times 10^6/V$$

where W = total mass of particulate matter received by a person (μg), W_f = filter paper mass after sampling (g), W_i = filter paper mass before sampling (g), V = standard air volume (m^3).

To find relative amounts of dust particles, of each size, dispersed in the air, we computed the correlation coefficients, r, for total masses of TPM *vs* PM_{10}, TPM *vs* $PM_{2.5}$ and PM_{10} *vs* $PM_{2.5}$ from burning common and smokeless incense in all sizes of rooms with and without ventilation.

Results and discussion

1. Amount of dust dispersed in the air

After warming up the sensors and before the incense was burnt, maximum background levels were TPM (79.60-94.30 μg/m^3), PM_{10} (58.36-70.43 μg/m^3) and $PM_{2.5}$ (25.43-28.17 μg/m^3) for the small room and TPM (80.46-96.36 μg/m^3), PM_{10} (67.4-74.06 μg/m^3) and $PM_{2.5}$ (26.97-29.01 μg/m^3) for the large room.

From Fig. 2, it was found that the average mass concentrations of TPM, PM_{10} and $PM_{2.5}$ inside the small room of common incense burning were 114.7, 90.6 and 34.8 μg/m^3, whereas for smokeless incense they were lower at 59.8, 50.6 and 23.0 μg/m^3, respectively. Similar factors were observed in the larger room: common incense burning had average mass concentrations of 100.6, 85.2 and 31.4 μg/m^3, whereas smokeless incense had averages of 77.8, 58.6 and 26.3 μg/m^3, respectively. In the non-ventilated rooms, similar ratios were found, but, as might be expected total concentrations where higher without ventilation. Further ventilation was more effective in 'clearing out' the smaller $PM_{2.5}$ particles.

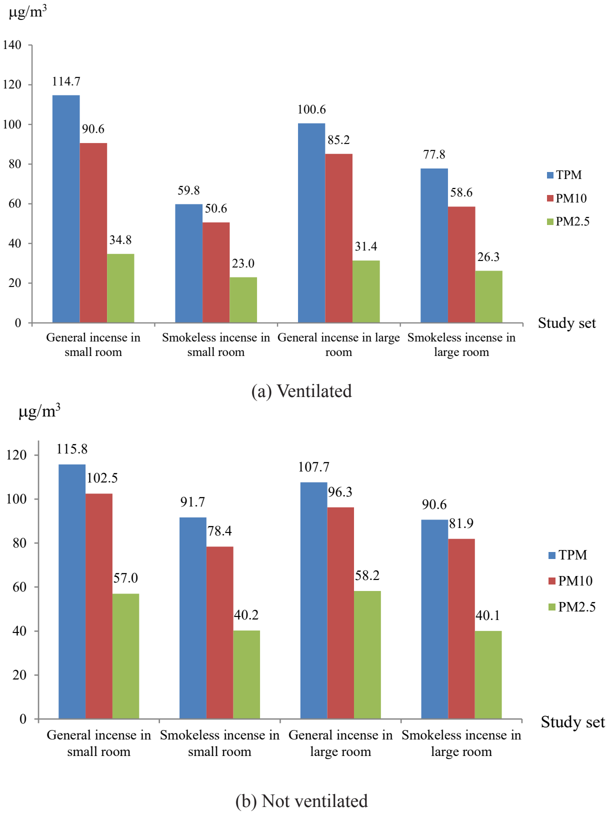


Fig. 2 Average mass of dust dispersed in a room (a) with and (b) without ventilation

TPM dust content from incense burning of all types of room sizes and every condition of the study room did not exceed the criteria, specified by the Department of Health (<150 μg/m^3), whereas PM_{10} and $PM_{2.5}$ particulate matter in all room sizes and conditions exceeded the more stringent Department of Health thresholds (PM10 < 50 μg/m^3 and $PM_{2.5}$ < 35 μg/m^3) However, $PM_{2.5}$ in the ventilated room only slightly met the threshold for common incense and for smokeless incense it was acceptable (~25 μg /m^3) in a ventilated room. Smokeless incense produced lower values of all particle sizes – averaging less than 10% compared to the common variety. Smokeless incense use should be encouraged in areas where large amounts of incense are likely to be burnt.

Our measurements confirmed that smokeless (or low smoke) incense did, in fact, emit lower amounts of particles. The smokeless incense is a solution to the weakness of common incense by changing the ingredients of incense sticks. Smokeless incense selects natural materials that are free from chemicals, such as corn cobs mixed with finely ground jasmine flowers so the incense smells soft. The part of the incense stick is made of bamboo that has been separated from wood vinegar for safety reduce toxics (George et al., 2022), thus causing the amount of dust generated from common incense burning to be higher than smokeless incense.

In addition, it was found that the amount of dust in the non-ventilated room was higher than the ventilated room. This may be due to the dust from the incense burning being an activity that takes place inside the building. The Department of Health (2016) stated that dust from accumulation in various areas of the building, if there is poor ventilation, may accumulate in the building and may be higher in quantity. When used to compare the amount of dust dispersed in the air from the common incense burning and smokeless incense in a room with and without ventilation using the static Paired samples t-test at the statistical confidence level of 95% found that the amount of dust dispersed in the air was significantly different. However, it was found that the particulate matter content of TPM, PM_{10} and $PM_{2.5}$ from incense burning in different room sizes and different conditions. This included the particulate matter of TPM and PM_{10} from the burning of smokeless incense in different conditions within the large room, which found that there was no significant difference. However, the amount of TPM and PM_{10} dust dispersed in the air from all types of incense burning is consistent with Chaipuettitanon (2013), who studied the concentration of TPM and PM10 particles inside buildings at Phanom Thuan Vocational College, where the TPM level in the electrical work building was ~2.3 µg/m^3 and the PM10 was 0.9 to 1.8 µg/m^3. As for the results of the study of $PM_{2.5}$ from incense burning, it was found to be different from the results of the study of Khawgrib et al. (2021) which studied the impact of $PM_{2.5}$ on building hygiene, it was found that the amount of $PM_{2.5}$ dust in the room with the doors and windows open had an average of 28-82 µg/m^3, which was exposed to outside air with an average of dust or various pollutants than a room that does not have open doors-windows with an average of 28-73 µg/m^3. The average dust in the room with the open system was significantly higher than the room with the closed system single source of pollutants in the room. Therefore, the ventilated room will have all doors and windows open.

The study on $PM_{2.5}$ emissions from incense burning yielded results that differed from Khawgrib et al. (2021)'s investigation into the impact of $PM_{2.5}$ on building hygiene, specifically focusing on the Chanthaburi national archives. In their case study, it was observed that a room with doors and windows open had an average $PM_{2.5}$ concentration ranging from 28 to 82 µg/m^3, which was higher than a room without open doors or windows, with an average concentration of 28 to 73 µg/m^3. The open system exposed the room to external air containing a higher level of dust and various pollutants compared to a closed system. Consequently, rooms with proper ventilation, characterized by open doors and windows, demonstrated significantly higher average dust concentrations than rooms with a closed system as the sole source of pollutants. Therefore, causing ventilation to be more convenient than a room with all doors and windows closed which does not have ventilation, resulting in dust generated from a single source, which is the incense burning in the room, there is more dust accumulation than the room with ventilation.

2. Total amount of particulate matter received by a person

Fig. 3 shows TPM received by a person, it was found that the average TPM of dust from common incense and smokeless incense in a small room with ventilation was 0.3472 and 0.2778 µg/m^3, respectively and were 0.4861 and 0.2430 µg/m^3, respectively for large room. The TPM dust content from common incense and smokeless incense without ventilation in small rooms were 0.7986 and 0.3125 µg/m^3, respectively, whereas, in the larger room, it was were 0.8361 and 0.5902 µg/m^3, respectively. The total received by a person from incense burning and smokeless incense in all room sizes and under all conditions did not exceed the acceptable criteria specified

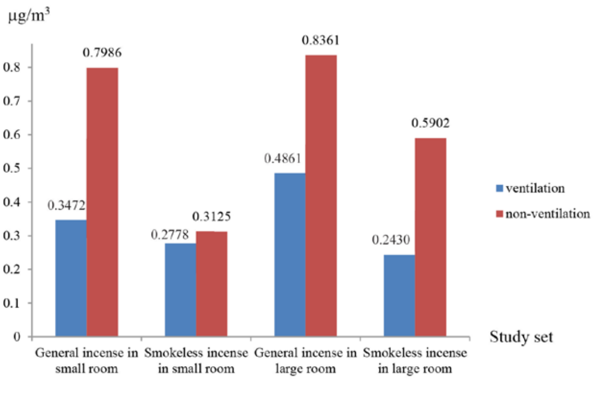


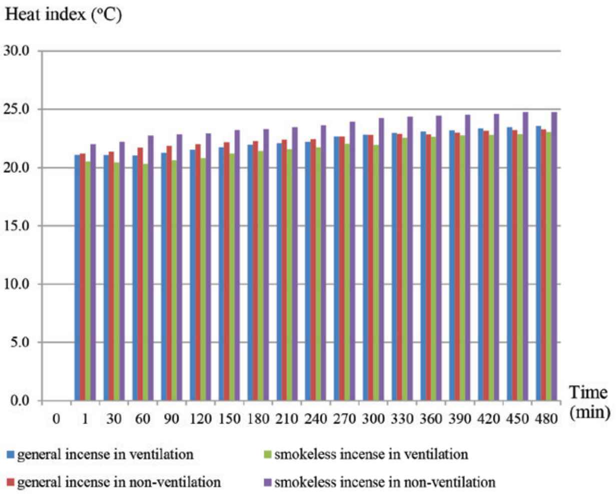
Fig. 3 Average TPM exposed by a person in a small and large room

by the Department of Health (2016): the value must not exceed 150 μg/m³.

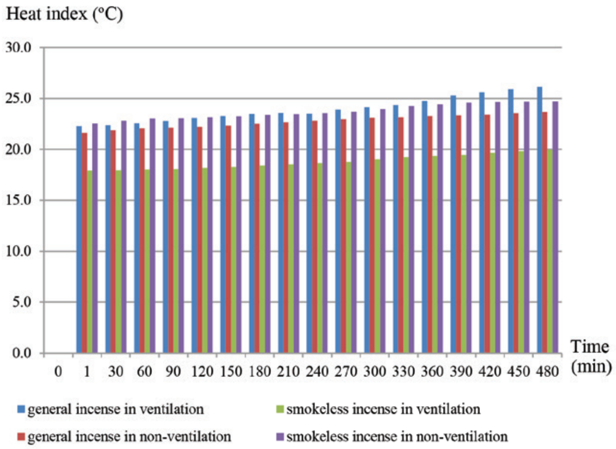
The TPM received by a person from common incense burning and smokeless incense in a small room with and without ventilation ranged from 0.2-1.1 μg/m³. Unsurprisingly, it was found that the TPM received in non-ventilated rooms was higher than in ventilated rooms. This is because the amount of dust compressed in an unventilated room will cause a higher accumulation of dust than a ventilated room (Department of Health, 2016). However, when comparing TPM received by a person with the Department of Health (2016) criteria, it was found that the TPM in all room sizes and conditions from burning both types of incense did not exceed the acceptable 150 μg/m³ criteria. Further, if the room was ventilated, the amount of dust that a person received was less than the specified threshold. This is consistent with Chaipuettitanon (2013), who assessed the exposure of particulate matters of staff and students in Phanom Thuan Industrial and Community Education College, Kanchanaburi Province, who found that teaching and learning activities that emphasized practice in various tasks, averaged 8 hr per day, generated a large amount of dust. The highest TPM exposure was found for automotive students, automotive teachers and electrical students (all ~2.0 μg/m³), with the lowest TPM exposure was accounting teachers (1.5 μg/m³). Automotive and electrical work students and teachers were exposed to high TSP, because they typically practiced for 6-8 hr together and dust was sourced from the practice. As a result, this group of students and teachers are likely to be exposed to high TPM levels over a long period, whereas accounting teachers were exposed to the lowest level of TPM, both in their office or classrooms and exhibited much lower dust generation activities.

3. Heat index study

Fig. 4 shows the average heat index (in every 30 min) from incense burning in a ventilated room from incense burning in a small room were 24.9°C (common) and 21.7°C (smokeless). For the large room, averages were lower at 23.9°C and 18.7°C, respectively. For the non-ventilated room, the average heat index of incense burning and smokeless incense in the small room was 23.5°C and 21.7°C, respectively, the large room had an average of 22.7°C with a value of 23.7°C, respectively.



(a) Small room



(b) Large room

Fig. 4 Average Heat index from incense burning inside (a) a small and (b) a large room

The heat index from incense burning in the rooms with and without ventilation studied, has an average heat index of 18.7-24.9°C, which is lower than the criteria announced by the Ministerial Regulations (2016) on setting standards in prescribing standards for administration such as managing and implementing occupational safety, health and work environment related to heat, light and noise. This may be due to the small amount of incense used to burn 45 incense sticks, the heat generated therefore does not affect the heat generated within every room size and all conditions studied normally, the heat index comes from work or the amount of work and the weight of the work on the part of human beings. Parts of the human body's internal temperature may change over a short period of time without affecting the functioning of the body. The heat that influences the heat in the human body comes from the heat generated within the body from metabolism to generate energy and heat from the outside environment.

4. Relationship between the size of dust diffusing from incense burning

We computed correlation coefficients showing the correlation between the various particle sizes: TPM vs PM_{10}, TPM *vs* $PM_{2.5}$ and PM10 *vs* $PM_{2.5}$ for incense burnt from common and smokeless incense in several sizes and conditions of rooms. It is noted that good correlations existed between amounts of particles of the various sizes under most conditions. Thus, if we are concerned to estimate potential health effects from burning incense, a single measurement can, with reasonable accuracy, predict the concentrations of the others. Therefore, a measurement from a simpler or cheaper instrument measuring TPM or PM_{10} can reasonably predict the hazard from the, potentially more dangerous, $PM_{2.5}$.

For the non-ventilated (closed) room, the worst correlation between the various particle sizes was r = 0.78. Given that the incense sticks used were inexpensive 'consumer' grade sticks, this represented a strong correlation. For the open room, overall correlations were good, generally r > 0.8 and some conditions led to r > 0.9. The worst correlation, r = 0.45, TPM *vs* $PM_{2.5}$. for the small, open room with common incense was attributed to random variations due to external influences – measurements were made on different days, because we were constrained to a single set of equipment. We noted that the worst correlations were observed for the largest variations in particle size, TPM *vs* $PM_{2.5}$, which is expected for higher variations in external air flows.

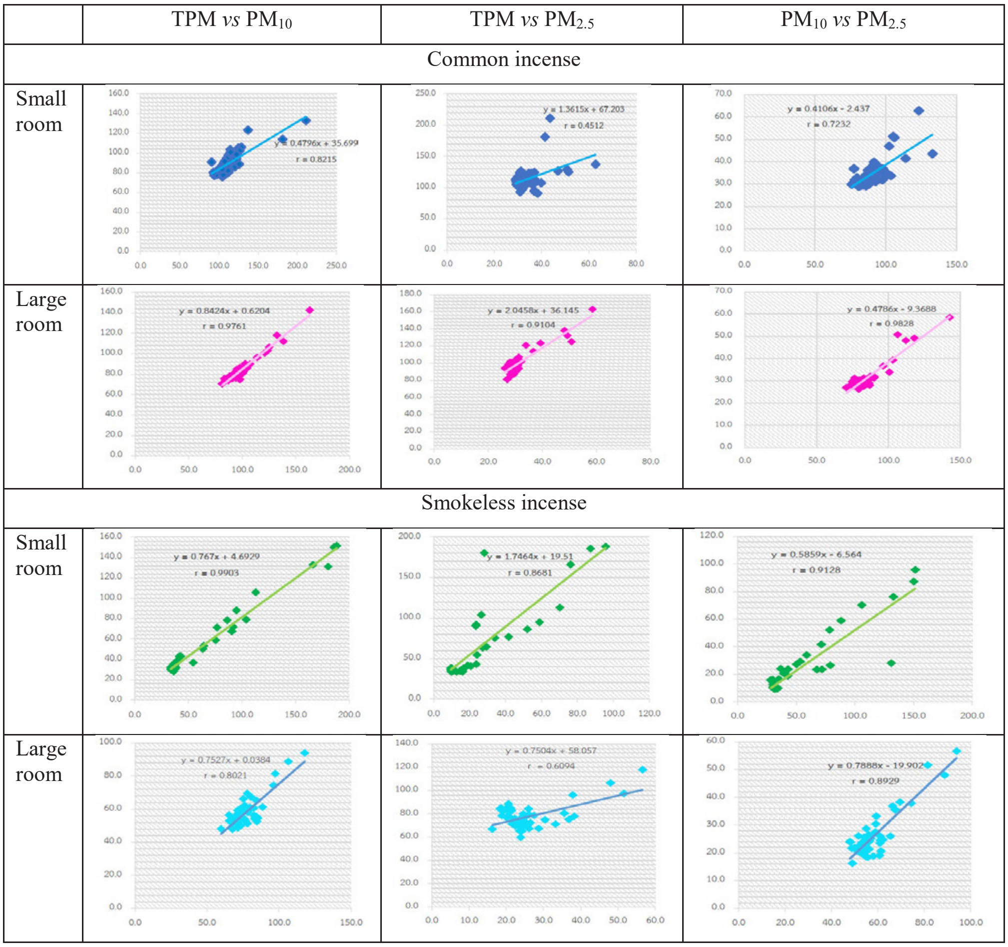


Fig. 5 Correlations between concentrations of various PM sizes: ventilated room

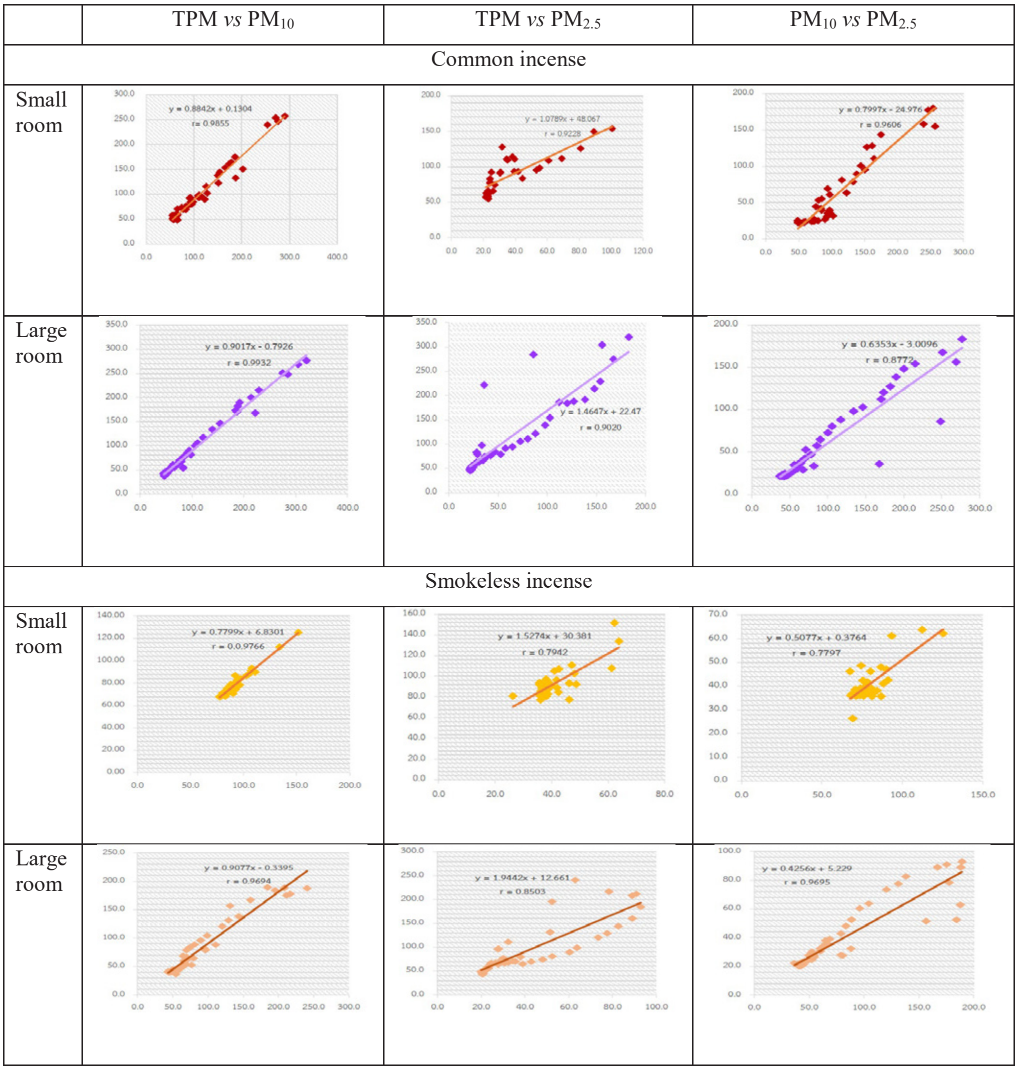


Fig. 6 Correlations between concentrations of various PM sizes: non-ventilated room

Currently, TPM concentrations are widely reported publicly – on TV and newspapers, etc. This study suggests that, as a source of visible pollutants, incense burning in well ventilated spaces is not likely to create a significant risk and people should not be overly concerned. However, in closed spaces, incense burning can lead to TPM levels exceeding public health guidelines. When TPM levels become a concern – a space that is well ventilated on a 'normal' day may become effectively 'closed' on a still day, the correlations between concentrations of various TPM sizes allow a single measurement to infer the overall risk. Inexpensive, reasonably accurate sensors are widely available now, whereas Dejchanchaiwong et al. (2023) discussed their accuracy and calibration. Thus, at least as far as the contribution from incense burning, a reasonable estimate of the health risk spectrum, i.e. TPM, PM_{10} and $PM_{2.5}$, in any given may be obtained to guide remediation, which should start with better ventilation and continue with regular monitoring, focusing on days when the room space have crowds, when higher amount of incense are burned.

Conclusion

We tested the effect of burning typical amounts of incense on concentrations of particulate matter in two rooms with different sizes, with and without unforced ventilation through open windows, to assess health effects as well as an index of comfort for an occupant. A general summary of observations follows:

• Burning 45 sticks (or 44-45 g or active material), TPM was within recommended guidelines, but PM_{10} and $PM_{2.5}$ generally exceeded the guidelines by small amounts, although smokeless incense was barely within the guideline for PM2.5 in a ventilated room.

• Common incense produced about 50% more particulate matter for all particle sizes.

• Although ventilation, as expected, reduced particulate matter concentrations, in the conditions tested in this study (open windows without forced convection), the benefit was not significant – only 1% reduction in one case and at best 40% smaller. This suggested that some form of forced ventilation should be considered.

• Correlations between TPM, PM_{10} and $PM_{2.5}$, derived from regressions, were sufficiently accurate that simple, inexpensive test devices could with, reasonable reliability, predict concentrations of, for example, $PM_{2.5}$ from incense from TPM measurements. Thus, given that regulations are only guidelines and should be considered with large safety margins, simple instruments can provide estimates of potentially dangerous situations and estimates improvements achieved by, for examples, improving ventilation.

• Loadings per person were less than 0.18 $\mu g/m^3$ (common) and 0.12 $\mu g/m^3$ (smokeless) in a closed room, but those levels in a ventilated room were 50% lower and much less than the standard 150 $\mu g/m^3$ standard.

• Heat index measurements showed that the incense loadings were insufficient to affect the functions of an individual in the room from the heat generated in burning incense alone.

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