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Exploratory assessment of indoor and outdoor particle number concentrations in Hanoi households

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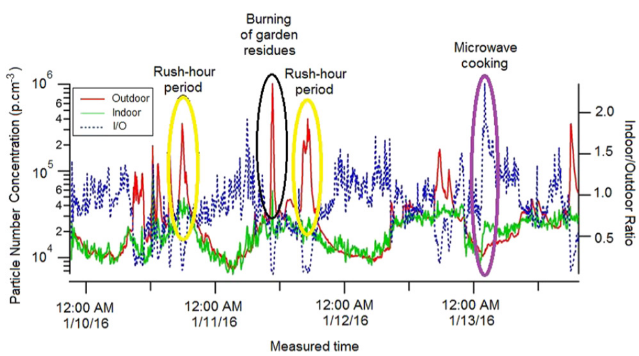
HIGHLIGHTS

- The first study to monitor both indoor and outdoor PN concentrations in Vietnam
- Indoor level ranged from 1.3–3.0 $\times 10^4$ p/cm^3 and outdoor level from 2.1–4.7 $\times 10^4$ p/cm^3
- Outdoor PN concentrations were influenced by vehicle emissions and rainfalls.
- Indoor PN concentrations were contributed by both indoor and outdoor sources.
- $PM_{2.5}$ concentrations were not indicative of PN concentrations.

GRAPHICAL ABSTRACT



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ABSTRACT

No studies have been conducted in Vietnam to understand the levels of atmospheric ultrafine particles, despite having adverse health effects. Information about indoor air quality in Vietnam is also limited. Hence we aimed to conduct the first assessment of ultrafine particle concentrations in terms of particle number (PN) in Hanoi, by simultaneously measuring indoor and outdoor PN concentrations from six households at different locations across the city in January 2016. We also acquired $PM_{2.5}$ data for this monitoring period from an air quality monitoring station located at the US Embassy in Hanoi, to compare the general trends between PN and $PM_{2.5}$ concentrations. The mean daily indoor and outdoor PN concentrations for the monitoring period were 1.9×10^4 p/cm^3 and 3.3×10^4 p/cm^3, respectively, with an increase during rush hour traffic. It was concluded that traffic was the main contributor to outdoor PN concentrations, with agricultural burning having a small influence at one study location. The mean ratio of indoor to outdoor PN concentrations for all six sites was 0.66 ± 0.26, which points to outdoor air as the main driver of indoor PN concentrations, rather than indoor sources. These PN concentrations and I/O ratios are similar to those reported for a number of cities in developed countries. However, in contrast to PN, ambient mean $PM_{2.5}$ concentrations in Hanoi (60–70 μg/m^3) were significantly higher than those typically recorded in developed countries. These findings demonstrate that urban particle mass ($PM_{2.5}$) concentrations are not indicative of the PN concentrations, which can be explained by different sources contributing to PN and PM, and that direct measurements of PN are necessary to provide information about population exposure to ultrafine particles and for management of air quality.

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1. Introduction

There is a growing interest in understanding concentrations of ultrafine particles (<0.1 μm), because of their potential to have adverse health effects on humans (Franck et al., 2011; HEI, 2013; Lanzinger et al., 2016). Ultrafine particles (UFPs) can be emitted from biomass burning (Reid et al., 2005) and photo-chemical formation (Pey et al., 2009). However, in urban areas, the source of UFPs is mainly attributed to vehicle emissions (Perez et al., 2010; Pey et al., 2008; Quang et al., 2012). Outdoor UFPs contribute to the indoor concentration, as they are brought inside the buildings through ventilation or via penetration through the building envelopes. At the same time, indoor activities, such as cooking and burning of candles can increase indoor UFP concentrations (Abt et al., 2000; Bekö et al., 2014; He et al., 2004; Meier et al., 2015). Increased indoor particle levels directly increase exposure to occupants of the building to UFPs.

UFPs are measured in terms of particle number (PN) concentration. It should be noted, however, that most of the instruments for measuring particle number concentrations cover a wide range of particle sizes, from ultrafine range to much larger particles depending on the instrument specification. Since the majority of the particles in terms of number are in the ultrafine size range, measurements of PN are considered a good representation of UFPs. In this study, we used Philips Aerasense NanoTracers to measure PN in the size range of 10 up to 300 nm. Nevertheless, for the sake of accuracy, in this manuscript we will refer to PN, rather than UFPs.

To our knowledge, there have been no studies reporting PN concentrations measured either indoor or outdoor in Vietnam including in large cities where combustion sources are expected to contribute significantly to their PN concentration level. Meanwhile, several studies have reported mass concentrations of PM_{10} and $PM_{2.5}$ in Hanoi, the capital of Vietnam, with >7 million inhabitants (Cohen et al., 2010; Hien et al., 2002; Kim Oanh et al., 2006; Saksena et al., 2008) as well as their impact on human health (Luong et al., 2017).

To provide at least a preliminary assessment of urban PN concentrations in Vietnam, this pilot study aimed to: (1) quantify the indoor and outdoor PN concentration at several residential houses in Hanoi; (2) - investigate factors influencing household indoor and outdoor PN concentrations; and (3) assess the association of daily outdoor PN concentrations with outdoor $PM_{2.5}$ concentrations in Hanoi.

2. Methods

2.1. Study area

This study was conducted in 2016 in Hanoi, which is a growing city in the North of Vietnam (21.02°N, 105,85°E). It has 30 urban and suburban districts covering an area of 3345 km^2, and has a population of 7.2 million (Statistic, 2015).

The city has the tropical monsoon climate, with hot and rainy summers (May to August) and winters are cold and dry (November to January). Located near the tropics, Hanoi receives abundant solar radiation (average of 122.8 kcal/cm^2) and has a relatively high annual average temperature (23.6 °C). The average annual relative humidity is 79% and the average annual rainfall is 1.800 mm (Statistic, 2015).

Motorbikes are the main mode of transport for the city commuters, with passenger cars becoming more popular in recent years. In the first eight months of 2015, the city saw 183,000 newly-registered vehicles (>39,000 cars and 143,000 motorcycles), bringing the total number of resisted vehicles to 5.5 million (about 535,000 cars and 4.9 million motorcycles) (Times, 2015). The passenger car fleet in Hanoi still includes many old and ill-maintained vehicles, and motorcycles emissions are not controlled in Vietnam (Times, 2015). Hence, traffic emissions are considered the main cause of air pollution in Hanoi.

2.2. Study design

Six urban residential houses were included in this study, covering different house styles and locations in Hanoi. They were assigned as sites S1 to S6 (Fig. 1). S1 - S4 are semi-detached houses. S5 and S6 are apartments in high-rise buildings. Information about the monitoring sites and the periods when the measurements were conducted at each site are presented in Table 1.

S1 and S2 are two neighbouring four-storey houses, located in a new urban area in southern Hanoi. They are about 120 m away from the main city ring-road with a daily traffic volume on the nearest road of about 83,000, consisting of 52,000 motorcycles (TEDI, 2007). S3 and S4 are four-storey houses located within the city centre. S3 is about 75 m from a busy road with daily motorbike and car traffic volumes of 31,000 and 11,000, respectively. S4 is close to a new main road (about 50 m away), connecting the city centre to the Hanoi International Airport, with estimated daily traffic volume of 55,000, dominated by cars (TEDI, 2007).

S5 is located in an apartment building in southern Hanoi. The building is close to the National Express Way No1B, with a traffic volume (>4 wheels) of about 34,000 per day (TEDI, 2007). In the vicinity of this site farmers on occasionally burn crop residue. The apartment building where S6 is located is in south-western Hanoi. This building is separated from a street by an identical building. The street has a total daily traffic volume of about 25,000, of which about 8000 are cars (TEDI, 2007).

At each site, simultaneous indoor and outdoor measurements of PN levels were conducted using two NT instruments (as described in Section 2.3) for 43–90 h (Table 1). At the same time, diary entries were completed by the occupants to record indoor activities that took place during the monitoring campaign. Due to security reason, all outdoor measurements at sites S1–4 were carried out at level 4 while indoor measurements were carried out at lower level in living rooms where most activities took place. At site S2, there was a short period of PN measurement in an unoccupied bedroom with tightly closed doors and windows to evaluate the impact of air exchange/infiltration on the measured PN concentration. At S5 and S6 the measurements were conducted on the eighth and the twelfth floor, respectively.

2.3. Instrumentation and quality assurance

Two Philips Aerasense NanoTracers (NTs) were used to measure PN concentrations. NT measures PN concentrations up to 1×10^6 p/cm^{-3} in

Table 1
Information of the monitoring sites and the respective measurement periods in January 2016.

Site	S1	S2	S3	S4	S5	S6
Monitoring period	5–7 Jan	7–9 Jan	16–18 Jan	18–20 Jan	9–13 Jan	13–16 Jan
Duration (h)	64	48	94	63	44	50
Weather	Cloudy	Cloudy	Light shower/cloudy	Cloudy	Clear sky/cloudy	Cloudy/light shower
House type	Semi-detached 4-storey house				Apartment in high-rise building	
Outdoor position	Level 4	Level 4	Level 4	Level 4	Level 8	Level 12
Indoor position	Level 2	Level 1–3	Level 1	Level 1	Level 8	Level 12
Distance to the nearest road (m)	120	120	75	50	100	Separated by a similar building
Traffic volume (vehicle/d)	83,000	83,000	42,000	55,000	34,000	25,000