Field measurements of $PM_{2.5}$ and ultrafine particles in residential houses

Naoki, Kagi
Assoc. Prof.
Tokyo Institute of Technology
Japan
kagi.n.aa@m.titech.ac.jp

Abstract

Purpose / Context - Particulate matter (PM) is one of the main indoor air pollutions, and it can cause a wide range of diseases that lead to a significant reduction of human life. This study aimed at investigating of characteristics of particle concentrations for $PM_{2.5}$ and size distribution during different activities in residential houses.

Methodology / Approach - This study was conducted between December 2013 and January 2014 in 7 houses. The measurements of indoor air were continuously in 24 hours and the instruments were kept in the living room or bed room. Mass concentrations for $PM_{2.5}$ were measured simultaneously with Dust Trak (TSI/8533). The number size distribution concentrations of particle (10–863 nm) were measured with a portable aerosol mobility spectrometer (PAMS, Kanomax/3300).

Results – In each house, the average of $PM_{2.5}$ concentration was 10-45 μg/m^3. The average of I/O ratio of $PM_{2.5}$ was about 0.5-1.5. Indoor $PM_{2.5}$ concentration in the living room was increased by using the gas stove, toaster oven in the kitchen and burning candles, incense sticks in the next room. Ultrafine particles with diameters in the range of 30-50 nm were generated by cooking, and the peak particle diameter of I/O ratio was around 50 nm.

Key Findings / Implications – The indoor aerosols could be affected by the difference of the ventilation equipment with air filters. The fine and ultrafine particle emissions from candles and incense sticks are generated in indoor.

Originality - This study demonstrated the increase of $PM_{2.5}$ concentrations and ultrafine particle concentrations in the living room due to cooking or other activities with the $PM_{2.5}$ monitor and PAMS.

Keywords - Indoor air quality, $PM_{2.5}$, Ultrafine particle, Size distribution, Emission source

Kagi, N. DOI: http://dx.doi.org/10.4225/50/5810734a61d71
HealthyHousing2016: Proceedings of the 7th International Conference on Energy and Environment of Residential Buildings, November 2016, edited by Miller, W., Susilawati, C. and Manley, K. Brisbane: Queensland University of Technology, Australia. DOI: http://dx.doi.org/10.4225/50/58107c8eb9c71

1. Introduction

Particulate matter (PM) is one of the main indoor air pollutions, and it can cause a wide range of diseases that lead to a significant reduction of human life. The size of particles has been directly linked to their potential for causing health problems. Ki-Hyun Kim (2015) summarized the basic evidence on the health effects of particulate matter in atmospheric environments. The health effects of PM_{10} and $PM_{2.5}$ are well known that an exposure to particulate matter is linked to adverse respiratory and cardiovascular health effects. As particles decrease in size, nano size particles are also hypothesized to increase acidity and their ability to penetrate into the lower airways.

Since most people spend the majority of their lives indoors, we are exposed to the aerosols in indoor air. Morawska et al. (2013) pointed out that the need for good characterization and quantification of exposure to indoor aerosols appears obvious. And it is essential for exposure control to confirm particle matter of outdoor origin that has penetrated indoors and particle matter generated by indoor sources so that characterization and emission of indoor sub-micron aerosols have been of great interest.

This study aimed at investigating of characteristics of particle concentrations for $PM_{2.5}$ and size distribution during different activities in residential houses. The $PM_{2.5}$ concentrations and number concentrations of size distributions and were monitored in 7 houses.

2. Methodology

2.1 Housed and sampling methods

The study was conducted between December 2013 and January 2014 in 7 houses. The characteristics of the houses are given in Table 1. The houses were situated in residential areas of Tokyo, Kanagawa and Chiba in Kanto region in Japan. Some houses were not equipped with mechanical ventilation systems. No houses were equipped with heating appliances that generate fine particles, such as kerosene or LPG as main fuel. The house E only had the heating and ventilation air conditioning system that had an air filter for reducing particulate matter and the air conditioning system operated all day during the measurement. The sampling points in indoor air were the living room or bed room. The measurements of indoor air were continuously in 24 hours and the instruments were kept in the living room or bed room. While outdoor air was measured for 10 min. 5 times a day, 10, 13, 16, 19 and 22 o'clock at outside of each house. The residents of each house recorded their behavior in the house, such as cooking, using the hair drier, and so on.

Table 1: Building characteristics and heating and ventilating systems in residences

Name	A	B	C	D	E	F	G
Date	12/29	12/31	1/3	1/5	1/9	1/12	1/15
Location	Setagaya, Tokyo	Fuchu, Tokyo	Ota, Tokyo	Kawasaki, Kanagawa	Odawara, Kanagawa	Chiba, Chiba	Meguro, Tokyo
Type	Detached	Housing complex	Housing complex	Housing complex	Detached	Detached	Housing complex
Structure	Wooden	RC	Steel frame	RC	Wooden	Wooden	RC
Measurement location	Living	Living	Living	Bed room	Living	Living	Living
Next room	Kitchen	Kitchen	Kitchen, bathroom	Bed room	Kitchen	Kitchen	Kitchen, bathroom
Number of residents	4	4	1	5	5	4	1
Pet	×	×	×	×	○	○	×
Mechanical ventilation	×	×	○	×	○	○	×
Heating system	Electric carpet	Air conditioning	Air conditioning Ceramic heater	Fan heater	Air conditioning Halogen heater	Floor heating	Air conditioning

2.2 Instrumentation

Mass concentrations for $PM_{2.5}$ were measured simultaneously with Dust Trak (TSI/8533). In this study, measurements were continuous with a time resolution of 1 min.

The number concentrations of particle number size distributions (10–863 nm) were measured with a portable aerosol mobility spectrometer (PAMS, Kanomax/3300). The PAMS is an electrical mobility size spectrometer designed for portable, mobile, or handheld aerosol sampling applications consisted of a small DMA and CPC. The particle number size distribution measurements were continuous, with a time resolution of 3 min.

Another environmental factors, such as temperature, relative humidity and CO_2 concentration were also measured with the data recorder (T&D/TR-75Ui) in parallel.

A summary of the measuring equipment is shown in table 2.

These instruments were located on the table in the living room or bed room. The outdoor air samplings for $PM_{2.5}$ and particle size destribution were performed by carring Dust Trak and PAMS to outside of the house.

Table 2: Measurement equipment

Element	Target	Measuring device
Relative mass concentration	Dp<2.5μm	DustTrak(TSI/8533)
Particle size distribution	10nm<Dp<433nm	PAMS(KANOMAX/3300)
General environmental factors	Temperature, humidity and CO_2 concentration	CO_2 recorder (T&D/TR-76Ui)

2.3 Emission source of particles in indoor

It is important for indoor particulate characteristics to investigate the indoor particulate emission sources by human activities in houses. Table 3 shows the indoor particle emission sources from the previous studies. These lists are informative to find out the emission sources of particulate matter from the field measurements in indoors. The emission sources of fine particles, ultrafine particles, $PM_{2.5}$ and so on were listed as indoor activeties, such as cooking, tobacco smoking, hairsplay, incense sticks and etc.

Table 3: Indoor particle emission sources

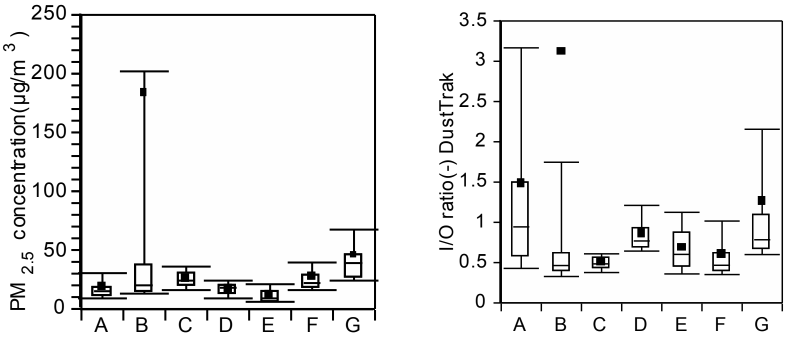
Source/cause	Characteristic particle	Measurement method	Refer.
Indoor activities (cooking, candle burning, aroma lamp, tobacco smoking, hair spray, incense sticks, open windows)	Particle indoor and outdoor sized 14-552 nm	Particle size spectrometer (SMPS 3934C, TSI Ine., USA)	Tareq Hussein et al. (2006)
Smoking and cooking	Inside and outside $PM_{2.5}$, $PM_{1.0}$, $PM_{0.5}$, and $PM_{0.25}$	Grimm aerosol spectrometer (Scattering light photometry and filter sampling)	D. Massey et al. (2009)
Gas for cooking	Inside and outside PN sized 7 nm-3 μm PM_{10} and $PM_{2.5}$	Condensation particle counter Gravimetric measurement using filter methods (Harvard impactors operating)	Gerard Hoek et al. (2008)
Cooking	$PM_{2.5}$	Scattered light photometry	Mohamed F. Yassin et al. (2012)
Cooking stove	Oil particle concentration sized $PM_{3.5}$	Scattered light photometry	A.C.K. Lai et al. (2008)
Human activities depending on time	Particle number sized 0.007-0.808 μm $PM_{2.5}$	Condensation particle counter Scattered light photometry	Lidia Morawska et al. (2003)
Indoor activities including cooking	Indoor/outdoor particle number size distributions (3-400 nm)	Particle size spectrometer	Tareq Hussein et al. (2005)
Printer emission	Nano particle from laser printer	Particle size spectrometer	Naoki Kagi et al. (2007)

3. Results

3.1 $PM_{2.5}$

Fig. 1 shows $PM_{2.5}$ concentrations and I/O (indoor/outdoor air concentration) ratios of $PM_{2.5}$ in each house measured with Dust Trak. The mean concentrations of each house were 10-45 μg/m^3 except for the house B. The rapid increases of $PM_{2.5}$, more than 50 μg/m^3 were obserbed by indoor activities in some houses. The I/O ratios in each house were usually less than 1 except for the house B. The I/O ratio of the house B was also at high level. Since the no-water burning of the kettle in the kitchen was occurred during the measurement, the mean $PM_{2.5}$ concentration and I/O ratio of the house B was extreme high rather than other houses.

Fig. 2 and fig. 3 show the time changes of $PM_{2.5}$ of indoor and outdoor air, temperature, relative humidity and CO_2 concentrations in the house A and E, respectively. The gas stove for cooking was used in the kitchen of house A from 17:00 to 19:00, and the rises of both $PM_{2.5}$ and the CO_2 concentrations was observed. The house E installed the induction heater (IH) for cooking. Since the particle emission from IH cooking was relatively low, the $PM_{2.5}$ concentration by cooking was at low level. But there was the increase of $PM_{2.5}$ concentration in indoor environment at 7:00 on the next morning, and the CO_2 concentration also rose at the same time. Because the candles and incense sticks in the next room of the living room were used in this time, these emission sources could raise $PM_{2.5}$ concentration in living room.



(a) $PM_{2.5}$ concentration (b) Indoor-to-outdoor ratios of $PM_{2.5}$

Fig. 1 Indoor $PM_{2.5}$ concentrations and I/O ratios by DustTrak in each house

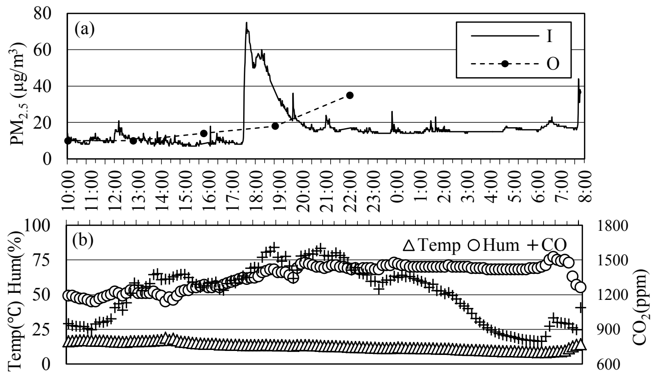


Fig. 2 Time changes of (a) $PM_{2.5}$ concentration and (b) temperature, relative humidity and CO_2 concentration in house A

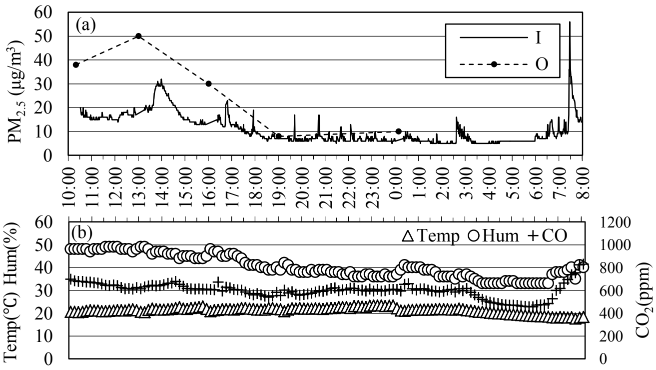
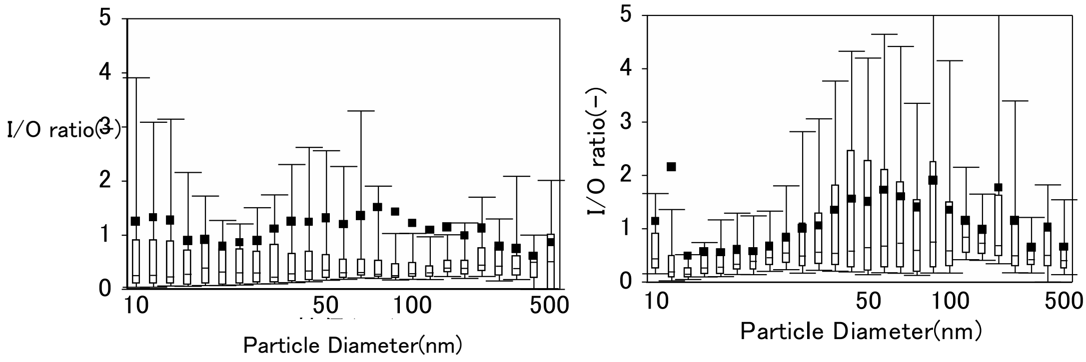


Fig. 3 Time changes of (a) $PM_{2.5}$ concentration and (b) temperature, relative humidity and CO_2 concentration in house E

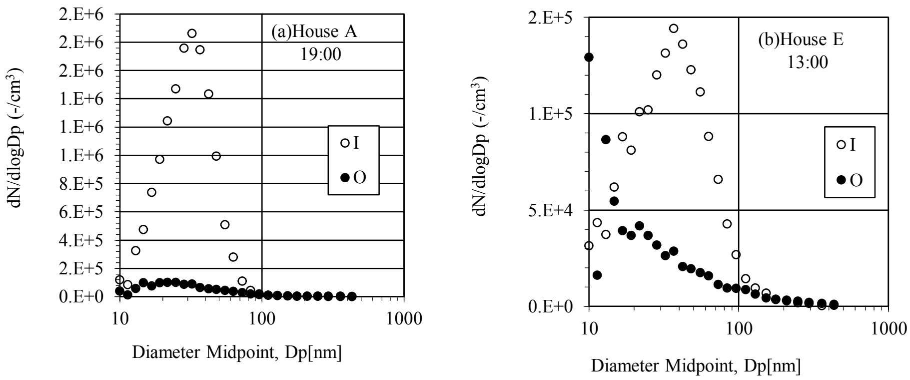
3.2 Particle size distribution

Fig. 4 shows the I/O ratio according to the particle size distribution in house A, E, respectively.

The peak diameter of the mean I/O ratio was around 50 nm, and 50 nm particles could be generated by the indoor activity in indoor. The characteristics of particle size distributions in indoor air could be affected by the difference of the ventilation equipment and the cooking equipment in the kitchen. Fig. 5 shows the size distribution of indoor and outdoor airborne particle during cooking in the house A and E. The main peak particle sizes in both houses were around 30 nm, in contrast to outdoor air. The gas stove and the toaster oven in the house A and E were used during sampling, a lot of 30 nm particles were generated by cooking.



(a) House A (b) House E
Fig. 4 Indoor-to-outdoor ratios of particle number concentrations versus particle size



(a) Gas stove at 19:00 in the house A (b) Toaster oven at 13:00 in the house E
Fig. 5 Size distribution of indoor and outdoor airborne particle during cooking

4. Discussion

The indoor aerosols could be affected by the difference of the ventilation equipment that equipped with air filters (Tran Ngoc Quang et al. 2013). The house E only had the heating and ventilation air conditioning system that installed an air filter. Fig. 1 (b) and fig. 3 showed the $PM_{2.5}$ concentrations in the house E. The mean $PM_{2.5}$ concentration was relatively low and the trend of $PM_{2.5}$ concentrations was also at low level except for particle emissions, such as burning the candle and incense stick.

E. Ge´hin et al. (2008) tested the fine and ultrafine particle emissions of candles and incense sticks and wide range of diameter, from 6 to 180 nm. The cooking activities also raise the $PM_{2.5}$ concentration not only in the kitchen, but also in the living room (Mohamed F. Yassin, 2012). This study demonstrated the increase of $PM_{2.5}$ concentrations and ultrafine particle concentrations in the living room due to cooking or other activities.

5. Conclusion

In this study, $PM_{2.5}$ and size distribution of ultrafine particles were monitored with Dust Trak and PAMS during different activities in 7 residential houses.

1) In each house, the average of $PM_{2.5}$ concentration was 10-45 μg/m^3. The average of I/O ratio of $PM_{2.5}$ was about 0.5-1.5.

2) Indoor $PM_{2.5}$ concentration in the living room was increased by using the gas stove, toaster oven in the kitchen and burning candles, incense sticks in the next room.

3) Ultrafine particles with diameters in the range of 30-50 nm were generated by cooking, and the peak particle diameter of I/O ratio was around 50 nm.

6. References

Hussein T. et al. (2006) Particle size characterization and emission rates during indoor activities in a house, *Atmospheric Environment*, 40, 4285-4307.

Kagi N., Fujii S., Horiba Y., Namiki N., Ohtani Y., Emi H., Tamura H., Kim Y. S. (2007) Indoor air quality for chemical and ultrafine particle contaminants from printers, *Building and Environment*, 42(5), 1949-1954.

Kim K., Kabir E., Kabir S. (2015) A review on the human health impact of airborne particulate matter, *Environment International*, 74, 136–143.

Hoek G. et al. (2008) Indoor-outdoor relationship of particle number and mass in four European cities, *Atmospheric Environment*, 42, 156-169.

Hussein T., Hameri K., Heikkinen M. S.A., Kulmala M. (2005) Indoor and outdoor particle size characterization at a family house in Espoo-Finland, *Atmospheric Environment*, 39, 3697-3709.

Lai A.C.K., Ho Y.W. (2008) Spatial concentration variation of cooking-emitted particles in a residential kitchen, *Building and Environment*, 43, 871-876.

Massey D., Masih J., Kulshrestha A., Habil M., Taneja A. (2009) Indoor/outdoor relationship of fine particles less than 2.5um (PM2.5) in residential homes locations in central Indian region, *Building and Environment*, 44, 2037-2045.

Mohamed F. Y., Bothaina E.Y., AlThaqe, E. A.E. (2012) Al-Mutiri Assessment of indoor PM2.5 in different residential environments, *Atmospheric Environment*, 56, 65-68.

Morawska L., Afshari,A. Bae G. N., Buonanno G., Chao C. Y. H., Hanninen O., Hofmann W., Isaxon C., Jayaratne E. R., Pasanen P., Salthammer T., Waring M., Wierzbicka A. (2013) Indoor aerosols: from personal exposure to risk assessment, *Indoor Air*.

Morawska L., He C., Hitchins J., Mengersen K., Gilbert D. (2003) Characteristics of particle number and mass concentrations in residential houses in Brisbane, Australia, *Atmospheric Environment*, 37, 4195-4203.

Yassin M. F., AlThaqeb B. E.Y., Al-Mutiri E. A.E. (2012) Assessment of indoor $PM_{2.5}$ in different residential environments, *Atmospheric Environment*, 5665-5668.

Quang T. N., He C., Morawska L., Knibbs L. D. (2013) Influence of ventilation and filtration on indoor particle concentrations in urban office buildings, *Atmospheric Environment*, 79, 41-52.