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Properties of Indoor Particles Collected in Japanese Homes

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ABSTRACT

Due to the heightened ambient $PM_{2.5}$ levels, the whole citizen of Japan, especially dwellers in Fukuoka Prefecture, start to make attention to the particulate matter (PM) of indoor environments. This study was aimed to thoroughly estimate the characteristics of indoor PM collected in five Japanese homes located in Fukuoka Prefecture. Simultaneous indoor measurements of PM were intensively made at five homes using filter-pack samplers, particle counters, and $PM_{2.5}$ monitors for a day in springtime, 2012. Major ionic and carbonaceous components were also analyzed. The time series fluctuation of PM number concentration was gradually decreased by 6 AM and then it was rapidly increased by 8 AM in all indoor sites. The maximum level of $PM_{2.5}$ was measured at the morning time (8 AM-9 AM) when the resident's behavior was fast and strenuous. The Indoor/Outdoor (I/O) ratio for the giant PM larger than 5.0 μm was 1.16. It was possible to identify PM types and estimate the resident's behavior through the comparison the theoretically calculated and the measured retention times for several types of PM in an indoor site. The theoretically reconstructed mass concentration of $PM_{2.0\text{-}0.3}$ suggested that the portion of $PM_{2.5}$ in indoor was quietly occupied by $PM_{0.3}$ or the PM inherently originated from indoor environment.

Key words: Indoor air pollution, Particulate matter, Health risk, $PM_{2.5}$, Fukuoka

1. INTRODUCTION

When people think about air pollution, they usually think about outdoor air pollution such as acid rain, smog, haze, ozone, and so on. But the air inside homes, offices, other buildings, and subway can be more polluted than the air outside (Ma *et al*., 2012; Salo *et al*., 2008; Chillrud *et al*., 2005). Although there is a difference among individuals, human beings spend most of their lifetime in indoor environments, especially house. Every gaseous and particulate pollutant that comes in to homes has the potential to be harmful to human health (Rebecca *et al*., 2004). Among them, very frequently identified components in home are soil, starch, hair, cotton, fungal material, synthetic fibers, polymers, paint, metals, asbestos, and so on (Fig. 1).

Some pollutants are brought into home through windows, doors, gaps (Fig. 1). As shown in Fig. 1, the pollutant materials and then locally transport in indoor reservoir space through the mechanisms as infiltration, exfiltration, indoor sources, track-in, surface deposition, and resuspension (Qian and Ferro, 2008). Meanwhile, some arrive via a new mattress or furniture, carpet cleaners, or a coat of paint on the walls. Consequently, the inhalation exposure to these indoor pollutants may result in a number of adverse health outcomes including respiratory effects such as asthma (Salo, *et al*., 2008; Wallace, 1996). Although this adverse health effect may strongly depend on resident activities, source events and site specificity, 10-30% of the total burden of disease from PM exposure is due to indoor-generated particles (Morawska *et al*., 2013).

In recent years, high levels of $PM_{2.5}$ were recorded in parts of western Japan, especially Fukuoka Prefecture (The Japan Times, 2013). Under the growing concern to this pollution crisis, the city of Fukuoka provides the real-time hourly $PM_{2.5}$ data on website. The city of Fukuoka also starts to warn its residents via personal cellular phone when $PM_{2.5}$ levels exceeds the safety standard. The central government's safety standard for $PM_{2.5}$ exposure is a mean of 35 $\mu g/m^3$ over a 24-hour period, and 15 $\mu g/m^3$ annually. The heightened $PM_{2.5}$ levels in Fukuoka are also call the whole citizen's attention to indoor air pollution.

Till now, the indoor air quality for gaseous organic components and particle number counts have been reported in Japan (Kanatani *et al*., 2014; Kagi *et al*., 2007; Sakai *et al*., 2004). However, the indoor PM in

urban houses has seldom been evaluated with respect to both size-resolved PM and their resuspension by human activity.

In light of this situation, we undertook a field campaign to evaluate the properties of indoor PM collected in the five homes located in Fukuoka, Japan.

2. MATERIALS AND METHODS

2.1 Location of Field Survey

An intensive collection and monitoring for size-resolved PM was conducted at five occupied houses in Fukuoka, Japan. Five houses have different resident number (from two to five), house type (i.e., terraced house, duplex house, and detached house), ventilation time (not mechanical ventilation but natural ventilation), and vacuuming time. The details on five selected houses are listed in Table 1.

The location of field study is indicated by filled circles in Fig. 2. Details on Fukuoka Prefecture were described in elsewhere (Ma and Kim, 2013). The site of Indoor-1 is a desolate area surrounded by resort beaches. Since our study was conducted during an off-season period there was no influx of people. However, there is a small-scale liner port, and small and large-scale regular lines are doing a shipping service near the site of Indoor-1. The site of Indoor-3 has six-lane roads with heavy traffic conditions. The sites of Indoor-2, 4, and 5 are residential area without any known point sources and heavy traffic.

2.2 Particle Collection and Monitoring

An intensive field survey of PM was simultaneously conducted at five houses for 24 h on May 21, 2012.

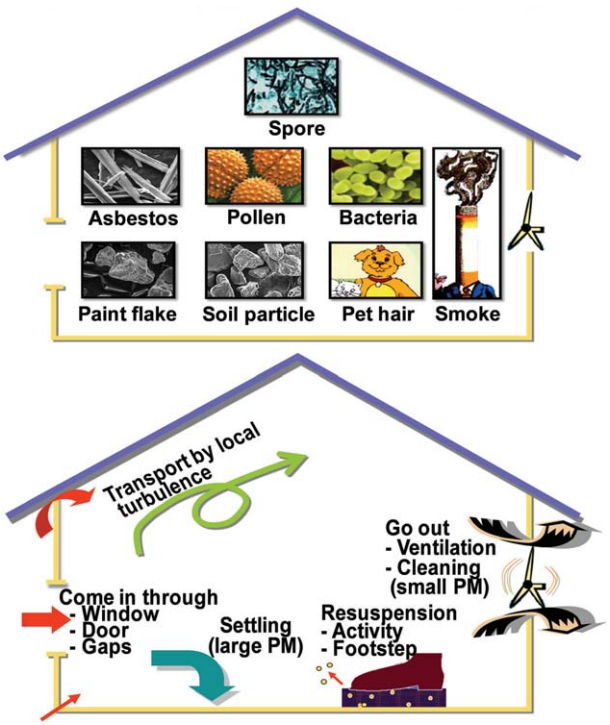

Fig. 1. Major PM kinds (top) and their behavior (bottom) in indoor.

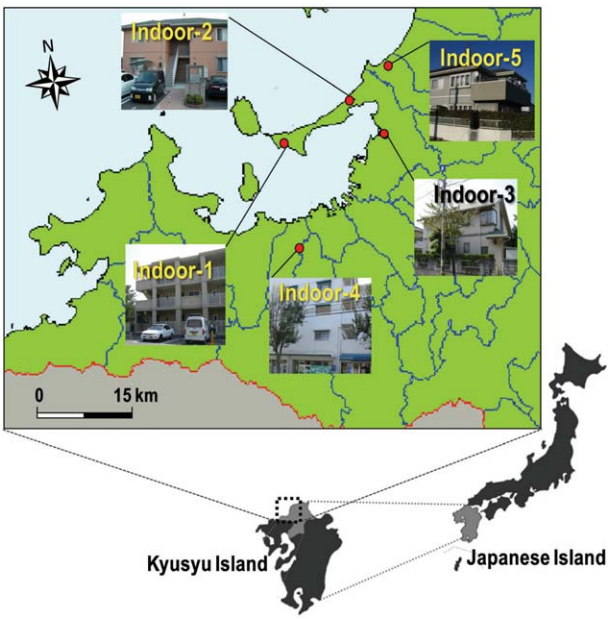

Fig. 2. Location of five houses selected for the study of indoor air pollution in Fukuoka Prefecture, Japan.

Table 1. Circumstances related PM concentration of each indoor site.

Site	No. of resident	House type	Flooring type	Pet	Ventilation/day[a]	Vacuuming/week	T (°C)	RH (%)
Indoor-1	2	Terraced house	Hardwood	Non	Not open	3 times	20.5	61.2
Indoor-2	2	Duplex house	Hardwood	Non	6 hr 40 min	1 time	20.2	60.6
Indoor-3	3	Detached house	Hardwood	Keeping	3 hr 30 min	5 times	19.8	57.0
Indoor-4	5	Duplex house	Hardwood	Keeping	2 hr 30 min	3 times	20.4	57.3
Indoor-5	4	Detached house	Hardwood	Keeping[b]	7 hr 10 min	2 times	20.3	57.8

[a]Pasive ventilation with opening windows
[b]Keeping at outdoor

For the sampling of $PM_{2.5}$, a total of five filter-pack samplers (URG, USA) were simultaneously operated. This filter pack sampler consists of a Teflon-coated aluminum cyclone with a cut size of 2.5 μm at a flow rate of 10 L min^{-1}, one stage filter pack, and a dual 47 mm diameter filter. In order to effectively determine both ionic and carbonic components, the dual filter (half Nuclepore® filter/half quartz filter (Tokyo Dylec Co.)) was handily made up in this study.

In order to measure $PM_{2.5}$ mass concentration, five light scattering $PM_{2.5}$ monitors (Dust scan Scouts, Rupprecht & Patashnick Co. Model 3020) were simultaneously operated at each site. Details on this $PM_{2.5}$ monitoring system was previously described (Ma and Kim, 2013).

The number concentrations of size-selective PM (i.e., 0.3-0.5 μm, 0.5-1.0 μm, 1.0-2.0 μm, 2.0-5.0 μm, and >5 μm) were monitored at both inside and outside of each home by optical particle counters (OPC) (RION, KC-01D). In the field survey, OPC was operated every two minute. In order to avoid the direct influence of the stirring up of PM by resident's behavior as well as to consider the effect of resident's health (adult's sitting height and height of children), every particle collection and monitoring device was installed at 1.25 m above floor. This is a little bit higher than the average height of Japanese seven years old boy (1.22 m) in 2011 (OECD, Society at a Glance, 2012).

2. 3 Sample Pretreatment and Analysis

2. 3. 1 Sample Pretreatment and Analysis of Major Ionic Species in $PM_{2.5}$

After sampling, the dual filters were placed in sterilized airtight petridishes and stored in a refrigerator until analysis. For ion analysis, the half Nuclepore® filters were extracted with deionized water (18.2 MΩ $\cdot cm^2/cm$) by an ultrasonic treatment. And then the extracted water was filtrated through a 25 mm diameter Nuclepore® filter with 0.08 μm pore size to remove insoluble fraction. Two blank filter were handled in the same manner as the samples.

In this study, three major ions in $PM_{2.5}$, i.e., ammonium, nitrate, and sulfate having the greatest ambient concentrations in $PM_{2.5}$ (Higo *et al.*, 2013) were the target of Ion Chromatography (IC) (Dionex DX-100) analysis. In order to demonstrate the reliability of the analyzed data, the QA (quality assurance)/QC (quality control) was conducted by analyzing a set of known standard species. The data obtained by 10-time repeated IC analyses were tested for precision by checking the relative standard deviation (% RSD, (SD/mean) × 100) of each concentration in standard solution (0.5, 1, and 2 mg/L). As a result, the RSD levels of NH_4^+, NO_3^-, and SO_4^{2-} were very low as 2.31-4.14%, 0.02-3.51%, and 1.05-3.68%, respectively. These low RSD levels i.e., very high reproducibility is a clear indication of a methodological soundness.

2. 3. 2 Identification of Carbonaceous Component in $PM_{2.5}$

The concentration of carbonaceous compositions (i.e., organic carbon (OC) and elemental carbon (EC)) was determined from the half quartz filters using the TOR® (DRI) Method. This TOR® method is a well-accepted technique in which the sample is progressively pyrolyzed with continuous detection of evolved carbon. Two 0.64 cm^2 punches were taken from all quartz filters and placed in the analyzer. OC was defined as all carbon that evolved from the sample without added oxygen when heated up to 550°C. Two additional temperature steps of 700°C and 800°C are made. EC was defined as all carbon that evolved from the sample when heated up to 800°C in 2% oxygen and 98% helium atmosphere after the OC was removed. A full detail of TOR® method was described in elsewhere (Chow *et al.*, 1993).

3. RESULTS AND DISCUSSION

3. 1 Time Series Variation of the Number Concentration of Size-resolved PM

The daily average number concentration of fine PM (0.3-2.0 μm) was marked the highest level at Indoor-2 located in residential area (303,247 #/L with 46 $\mu g/m^3$ of $PM_{2.5}$), followed by the roadside home (Indoor-3) (200,245 #/L with 23 $\mu g/m^3$ of $PM_{2.5}$), at Indoor-5 in residential area (182,273 #/L with 22 $\mu g/m^3$ of $PM_{2.5}$), at the desolate home (Inoor-1) (147,554 #/L with 19 $\mu g/m^3$ of $PM_{2.5}$), and another home (Indoor-4) of residential area (92,735 #/L with 11 $\mu g/m^3$ of $PM_{2.5}$). This result is against expectation and the reason might be that several parameters, such as emission sources, ventilation period, vacuuming time, the number of residents, and behavior of resident, were complicatedly worked to determine the daily average number concentration of fine PM and $PM_{2.5}$ mass. For example, although the Indoor-2 is located at residential area, it ranked the maximum level of number and mass concentration of fine PM. This might be derived from a relatively long ventilation time (6 hr 40 min) and the lowest vacuum (one time per week).

Fig. 3 shows the time series variation of the average number concentration of size-resolved PM collected in five-indoor sites. One of conspicuous characteristics of this time series fluctuation of PM number concentration is that the number concentration was grad-

ually decreased by 6 AM and then it was rapidly increased by 8 AM. About this phenomenon, details will be dealt with more specifically in the next chapter.

The numbers in Fig. 3 indicate the Indoor/Outdoor (I/O) ratios of the average number concentration measured in this study. The average I/O ratios for fine PM ($PM_{1.0\text{-}0.3}$) varied from 0.40 to 0.41. This means that the daily average indoor PM concentration was below 50% of the outdoor level for submicron PM. In the case of coarse $PM_{5.0\text{-}1.0}$, it fluctuated from 0.67 to 0.75. Meanwhile, the I/O ratio for the giant PM larger than 5.0 μm was above 1.00 (1.16). Household PM may be accumulated from both internal and external sources over long periods of time. This I/O ratio was therefore probably dependent on passive and active ventilations

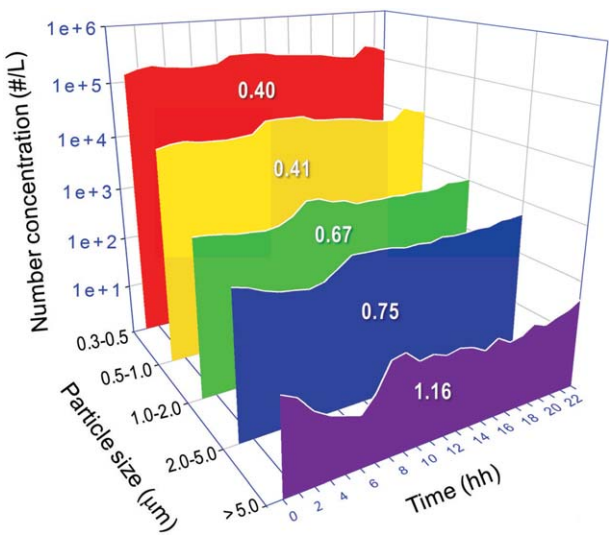

Fig. 3. Time series variation of the average number concentration of size-resolved PM collected five-indoor sites. The numbers in figure indicates the ratios of the average number concentration measured in this study to that of outdoor.

of house. Our result is well compared to that of Park *et al*. (2014). In their work, in the apartments with natural ventilation, I/O ratios of PM number concentrations ranged from 0.56 to 0.72 for submicron particles, and from 0.25 to 0.60 for particles larger than 1.0 μm.

3.2 Identification of PM Types and the Estimation of the Resident's Behavior by the Retention Time of PM

Activities such as folding blankets, folding clothes, dry dusting, walking on floor, vacuuming, and sitting on upholstered furniture can cause the resupension of PM in indoor. Most of the resuspended PM from these activities was larger than 5 μm in diameter (Ferro *et al*., 2004). Qian and Ferro (2008) performed a full-scale chamber experimental for investigating PM resuspension from human activities with the 0.1-10 μm test particles and reported the higher resuspension rates associated with larger particles. The source strengths were found to be the functions of the number of resident performing the activity, the strenuosity of the activity, the type of behavior, and the type of flooring (Qian *et al*., 2014; Ferro *et al*., 2004).

At closed indoor space, the timely variation of retention time of PM can be used for the identification of PM kinds and the estimation of the resident's behavior. The retention time of PM (i.e., the time taken from the highest PM concentration to a background state) may be decided by the physical properties of PM resuspened in the stable and closed indoor space. Indoor-4 that kept closed state during morning when PM number concentration was conspicuously fluctuated was selected.

Fig. 4 shows the detailed plotting of the number concentration of PM larger than 5 μm and their retention time in Indoor-4. The retention time of PM (>5 μm) varied from 10 to 30 min. This indicates that var-

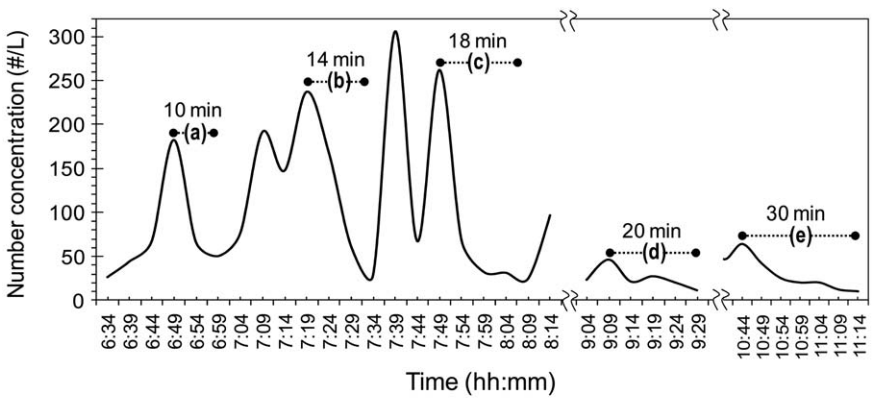

Fig. 4. Detailed plotting of the number concentration of PM larger than 5 μm and their retention time in Indoor-4.

ious PM types were resuspended in Indoor-4.

An influx of soil by tracked-in outdoor to the indoor environment has the potential to pose a significant human health (Hunt and Johnson, 2012). Since all houses selected to our field study is closer to sea, an indoor distribution of sea-salt is also considered. Although, coarse PM is easily resuspended by resident's behavior, the retention times of submicron PM (i.e., H_2SO_4 (diameter (d_p): 0.2 μm, particle density (ρ_p): 1,840 kg/m^3), black carbon (d_p: 0.5 μm, ρ_p: 90 kg/m^3), $(NH_4)_2SO_4$ (d_p: 0.75 μm, ρ_p: 1,770 kg/m^3), NH_4NO_3 (d_p: 0.75 μm, ρ_p: 1,730 kg/m^3) considered harmful to resident's health were also calculated with soil origin PM ($CaCO_3$) (d_p: 5.0 μm, ρ_p: 2,700 kg/m^3), sea-salt (NaCl) (d_p: 5.0 μm, ρ_p: 2,170 kg/m^3), and synthetic fiber driven from cloth (d_p: 5.0 μm, ρ_p: 1,250 kg/m^3). The terminal falling velocities (V_t) (i.e., the particle quickly reaches a constant velocity) of above 7 types of PM were calculated by below equation.

$$V_t(m/s) = \frac{g(\rho_p - \rho_f)d^2_p}{18\mu_f}$$

where g is the gravitational force (9.807 m/s^2), d_p is particle diameter, ρ_p is particle density, ρ_f is fluid (air) density (1.2 kg/m^3 at 20°C), and μ_f is fluid (air) viscosity (Hawker, 2001).

After calculating V_t, the retention time, i.e., the required time for particle deposition from ceiling (a 3.0 m height in Indoor-4) to a 1.25 m height above floor, was calculated by 1.75 m/V_t. Fig. 5 shows the theoretically calculated terminal falling velocity and the retention time for seven-type of PM. As shown in Fig. 5, the retention times of H_2SO_4, black carbon, $(NH_4)_2SO_4$, NH_4NO_3, $CaCO_3$, NaCl, and synthetic fiber were calculated as 13,092 min 18 sec, 39,889 min 28 sec, 968 min 13 sec, 990 min 37 sec, 14 min 17 sec, 17 min 46 sec, and 30 min 52 sec, respectively.

By comparing these theoretically calculated retention times for several different types of PM and the measured retention time of PM in Indoor-4, it is possible to roughly identify PM types and estimate the resident's behavior under the precondition that there was no additional resident's behavior during the retention time for several types of PM.

The measured retention times during 07:19-07:33 AM, 09:09-09:29 AM, and 10:44-11:44 AM (i.e., 14 min, 18 min, and 30 min) are closely matched to some of the calculated retention times (i.e., 14 min 17 sec, 17 min 46 sec, and 30 min 52 sec, respectively). Although, there are still many questionable points to achieve an understanding of PM retention, the PM being floated during three intervals (i.e., 07:19-07:33 AM, 09:09-09:29 AM, and 10:44-11:44 AM) were probably soil particles, sea-salts, and synthetic fibers, respectively.

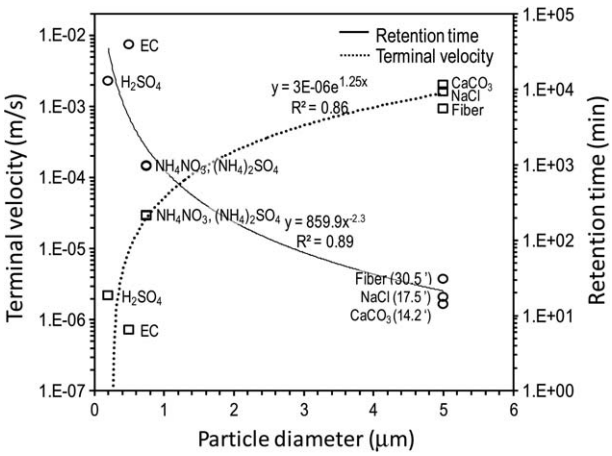

Fig. 5. Theoretically calculated terminal falling velocity and retention time for seven-type of particles.

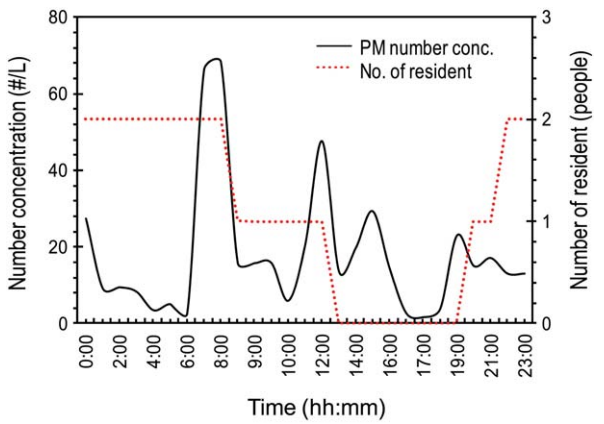

Fig. 6. Time series variation of coarse particle (>5 μm) number concentration according to the number of resident at Indoor-1.

It might be expected that the number of resident can generate a significant difference in PM resuspension in indoor environment. Here, the links between the time series variation of coarse PM and the number of resident was assessed. Fig. 6 shows the time series variation of coarse PM (>5 μm) number concentration for an all-day according to the number of resident at Indoor-1. In this Indoor-1, there was no considerable variation of the resident's daily life and no ventilation of both active and passive. As shown in Fig. 6, PM number concentration was fluctuated sharply and it was not perfectly proportional to the number of resident. The reason might be that the PM resuspension in indoor environment is related not only to the num-

ber of resident, but also different types and intensities of human activities.

During the night (1:00 AM-6:00 AM), PM number concentration showed a very low level (6 #/L). Meanwhile, although the number of resident was not altered, it remarkably increased to 67 #/L in the morning (6:00 AM-8:00 AM). Under the same condition of resident's number, in comparison to the night time (10:00 PM-11:00 PM), PM in indoor was vigorously resuspened in the morning time (6:00 AM-8:00 AM). This result might have relevance to the resident's behavior, i.e., the resident's footstep was more heavily and actively early in the morning as compared to night time. Elsewhere, the PM resuspension in indoor cloud be affected by various factors such as physicochemical characteristics of PM, textile properties of resident's clothes, and relative humidity in indoor, etc. On the other hand, the varying of PM number concentration during resident's absence (1:00 PM-7:00 PM) was probably caused by the inflow of outdoor PM through the chinks in the window or door. This indicates that both human activities (i.e., different types and intensities of resident's behavior) and PM inflow from outdoor are important to PM floating in indoor environment.

3.3 Theoretical Reconstruction of Mass Concentration of $PM_{2.0\text{-}0.3}$ in Indoor

As mentioned earlier, the issue of $PM_{2.5}$ exposure and its potential health effect is the essential concern for inhabitants, especially in the western Japan. This fine PM may cause the largest damage to the respiratory system because of their deposition in the respiratory tract including lung and their ability to remain in body for a long period of time. Fine PM also contains more carcinogens, mutagens, and environmentally disruptive chemicals than larger particles suspended in air (McDonnell *et al.*, 2000).

It is necessary to understand the origin of $PM_{2.5}$ in indoor environment for the assessment of its health risk. In this study, for the source profile of $PM_{2.5}$ as well as the estimation of its time series variation, the mass concentration of $PM_{2.0\text{-}0.3}$ ($M_{PM2.0\text{-}0.3}$) was theoretically reconstructed by the equation below.

$$M_{PM2.0\text{-}0.3}(\mu g/m^3) = \sum_{i=1}^{n}\left[\frac{\pi}{6} dx_i^3 \cdot \rho x_i \cdot \frac{x_i \cdot M.W.x_i^{-1}}{\sum(x_i \cdot M.W.x_i^{-1})} \cdot N_{PM2.0\text{-}0.3}\right]$$

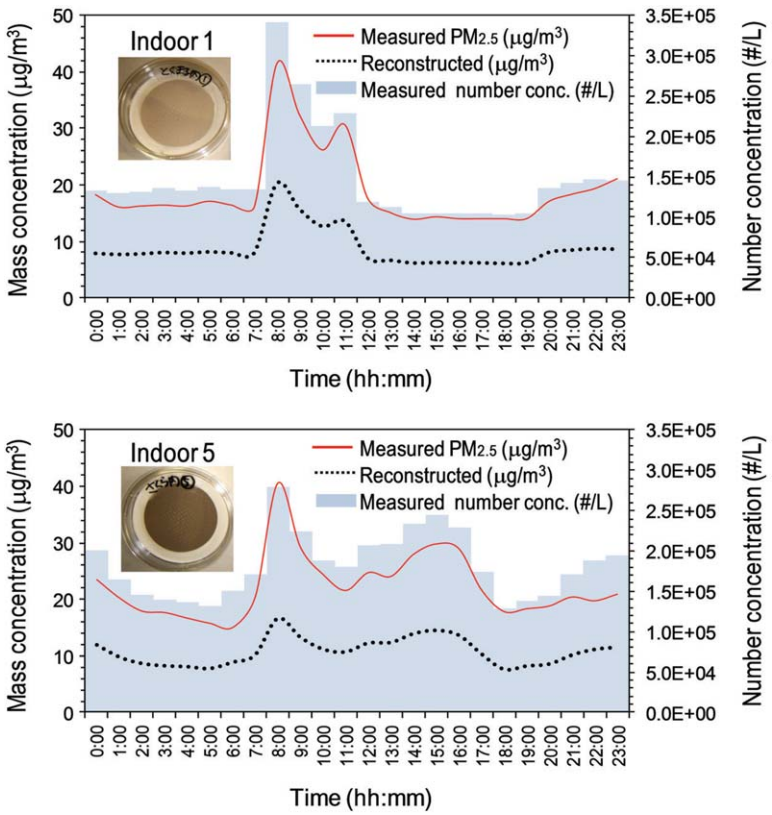

Fig. 7. Timely fluctuation of measured $PM_{2.5}$, the theoretically reconstructed mass concentration of $PM_{2.0\text{-}0.3}$, and the number concentration of $PM_{2.0\text{-}0.3}$ in two indoor sites. Inner photos are the views of filters after sampling.

where x_i is four-major particle types (n=4) of $PM_{2.5}$ in Fukuoka, d is diameter of x_i, ρ is density of x_i, $M.W._{x_i}$ is molecular weight of x_i, and $N_{PM2.0\text{-}0.3}$ is number concentration of PM ranged 0.3-2.0 μm.

Airborne PM is likely to be irregular in shape and non-spherical. In here, therefore, d (i.e., the diameter of x_i) is the aerodynamic particle size of the sphere that has the same drag coefficient as a given particle (i.e., x_i).

Higo *et al*. (2013) reported that the major components of $PM_{2.5}$ collected at 14-outdoor sites in Fukuoka were sulfate, nitrate, EC, and OC and their sum accounted for 82% of $PM_{2.5}$. Therefore, in this study, $(NH_4)_2SO_4$, NH_4NO_3, EC, and OC were selected as x_i. An x_i molar concentration was calculated from the concentration of each ionic and carbonaceous species analyzed in this study.

Two indoor sites, i.e., Indoor-1 without ventilation and Indoor-5 with the longest passive ventilation were the target of $M_{PM2.0\text{-}0.3}$. Fig. 7 shows the timely fluctuation of measured $PM_{2.5}$, the theoretically reconstructed mass concentration of $PM_{2.0\text{-}0.3}$, and the number concentration of PM ranged 0.3-2.0 μm in both Indoor-1 and Indoor-5 sites. In Indoor-1, the daily average $PM_{2.5}$ was 19.0 μg/m^3 and it ranged from 13.9 to 41.5 μg/m^3. In the case of the daily average fine $PM_{2.0\text{-}0.3}$ number concentration was 147,553/L and it varied from 102,710 to 264,332/L. Meanwhile, in Indoor-5, the daily average $PM_{2.5}$ mass and $PM_{2.0\text{-}0.3}$ number concentration were 22.3 μg/m^3 (14.9-40.5 μg/m^3) and 182,272/L (128,859-234,208/L), respectively. Relatively higher $PM_{2.5}$ mass and fine PM number concentration in Indoor-5 were probably caused by a large number of residents, a long-term ventilation, and a low vacuum situation compare to Indoor-1. The color of the filter after sampling displayed in Fig. 7 is more blackish in Indoor-5 than that of Indoor-1. This reasonably suggests that the fine PM in Indoor-5 contained a large amount of PM driven from internal-combustion engine like diesel cars. This result is also supported by a long passive ventilation time (7 hour 10 minutes).

Although there was a little different time series variation of $PM_{2.5}$ between two indoor environments, the maximum level of $PM_{2.5}$ in both indoor sites was formed at the morning time (8:00 AM-9:00 AM) when the resident's behavior was fast and strenuous. In Indoor-1, the daily average of $M_{PM2.0\text{-}0.3}$ accounts for 45.63% of the measured $PM_{2.5}$ and it varied from 39.72 to 49.42%. On the other hand, in Indoor-5, it accounts for 48.80% of the measured $PM_{2.5}$ with a range from 40.79 to 59.36%. The $M_{PM2.0\text{-}0.3}$ of both Indoor-1 and Indoor-5 are far lower than the measured $PM_{2.5}$. This suggests that the portion of $PM_{2.5}$ in both indoor sites was largely occupied by $PM_{0.3}$. Added to this, the dissimilarity between the measured $PM_{2.5}$ and the $M_{PM2.0\text{-}0.3}$ might be derived by the portion of $PM_{2.5\text{-}2.0}$. Otherwise, other distinctive indoor x_i having higher density (e.g., small size soil PM) than $(NH_4)_2SO_4$, NH_4NO_3, EC, and OC were probably floated in indoor environments.

4. CONCLUSIONS

In recent years, in the western Japan, especially Fukuoka Prefecture, a great deal of attention is paid to indoor air pollution with very strict regulation of $PM_{2.5}$. Motivated by growing considerations of the severity, and risks associated with human exposure to indoor PM, this study performed a combined experimental and theoretical studies to investigate the properties of indoor PM collected five occupied, single-family houses located in Fukuoka, Japan. Although the numerical limitation of indoor discussed in the present study is apprehensive, it is possible to summarize the results of our study as follow. On the contrary to the giant PM larger than 5.0 μm, the daily average number concentration of indoor $PM_{5.0\text{-}0.3}$ was largely lower than the outdoor level. The time series variation of coarse particle ($>$5 μm) number concentration indicates that the resident's behavior and footstep were more heavily and actively early in the morning as compared to night time. The theoretically reconstructed mass concentration of $PM_{2.0\text{-}0.3}$ suggested that the portion of $PM_{2.5}$ in indoor was quietly occupied by $PM_{0.3}$ or the PM distinctly emitted from indoor environment. So many parameters, such as emission sources, ventilation period, vacuuming time, the number of residents, and behavior of resident, were complicatedly worked to determine the daily average number concentration of fine PM and $PM_{2.5}$ mass.

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REFERENCES

Chillrud, S.N., Grass, D., Ross, J.M., Coulibaly, D., Slavkovich, V., Epstein, D., Sax, S.N., Pederson, D., Johnson, D., Spengler, J.D., Kinney, P.L., Simpson, H.J., Brandt-Rauf, P. (2005) Steel dust in the New York City

subway system as a source of manganese, chromium, and iron exposures for transit workers. Journal of Urban Health 82, 33-42.

Chow, J.C., Watson, J.G., Pritchett, L.C., Pierson, W.R., Frazier, C.A., Purcell, R.G. (1993) The DRI thermal/optical reflectance carbon analysis system: description, evaluation and applications in US air quality studies. Atmospheric Environment 27A, 1185-1201.

Ferro, A.R., Kopperud, R.J., Hildemann, L.M. (2004) Source strengths for indoor human activities that resuspend particulate matter. Environmental Science and Technology 38(6), 1759-1764.

Fukuoka issues warning on high $PM_{2.5}$ levels (2013) The Japan Times, http://www.japantimes.co.jp/news.

Hawker, D. (2001) Datalog drilling fluid hydraulics manual, Version 2.1. Anca Maria Anistoroae, pp. 24-29.

Higo, H., Yamashita, S., Kinoshita, M. (2013) Chemical composition and source apportionment of $PM_{2.5}$ in Fukuoka City. Annual Report of Fukuoka City 38, 53-57.

Hunt, A., Johnson, D.L. (2012) Suspension and resuspension of dry soil indoors following track-in on footwear. Environmental Geochemistry and Health 34(3), 355-363.

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, 1949-1954.

Kanatani, K., Okumura, T., Tohno, S., Adachi, Y., Sato, K., Nakayama, T. (2014) Indoor particle counts during Asian dust events under everyday conditions at an apartment in Japan. Environmental Health and Preventive Medicine 19(1), 81-8, doi:10.1007/s12199-013-0356-4.

Ma, C.J., Matuyama, S., Sera, K., Kim, S.D. (2012) Physicochemical properties of indoor particulate matter collected on subway platforms in Japan. Asian Journal of Atmospheric Environment 6, 73-82.

Ma, C.J., Kim, K.H. (2013) Artificial and biological particles in the springtime atmosphere. Asian Journal of Atmospheric Environment 7, 209-216.

McDonnell, W.F., Nishino-Ishikawa, N., Petersen, F.F., Chen, L.H., Abbey, D.E. (2000) Relationships of mortality with the fine and coarse fractions of long-term ambient SPM concentrations in nonsmokers. Journal of Exposure Analysis and Environmental Epidemiology 10, 427-436.

Morawska, L., Afshari, A., Bae, G.N., Buonanno, G., Chao, C.Y.H., Hänninen, 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 23, 462-487.

Park, J.S., Jee, N.Y., Jeong, J.W. (2014), Effects of types of ventilation system on indoor particle concentrations in residential buildings. Indoor Air. doi:10.1111/ina.12117.

Qian, J., Ferro, A.R. (2008) Resuspension of dust particles in a chamber and associated environmental factors. Aerosol Science and Technology 42, 566-578.

Qian, J., Peccia, J., Ferro, A.R. (2014) Walking-induced particle resuspension in indoor environments. Atmospheric Environment 89, 464-481.

Rebecca, M.M., Jennifer Bailey, J., White, P.A. (2004) The mutagenic hazards of settled house dust. Mutation Research 567, 401-425.

Sakai, K., Norbäck, D., Mi, Y., Shibata, E., Kamijima, M., Yamada, T., Takeuchi, Y. (2004) A comparison of indoor air pollutants in Japan and Sweden: formaldehyde, nitrogen dioxide, and chlorinated volatile organic compounds. Environmental Research 94, 75-85.

Salo, P.M., Arbes, S.J., Crockett, P.W., Thorne, P.S., Cohn, R.D., Zeldin, D.C. (2008) Exposure to multiple indoor allergens in US homes and its relationship to asthma. Journal of Allergy and Clinical Immunology 121, 678-684.

Society at a Glance: Asia/Pacific (2012) OECD, http://www.oecd-ilibrary.org/social-issues-migration-health/society-at-a-glance-asia-pacific-2011_9789264106154-en

Wallace, L. (1996) Indoor particles. Journal of the Air & Waste Management Association 46, 98-126.

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