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Relationship between Indoor and Outdoor Particulate Matter Concentrations in Japan

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ABSTRACT

We briefly show the results of indoor and personal $PM_{2.5}$ measurements in an epidemiologic study designed to evaluate the health risks of ambient $PM_{2.5}$ in Japan and the relationship between indoor and outdoor PM concentrations. The impact of indoor and outdoor PM pollution on health is described based on one morbidity study. The results of other studies on indoor $PM_{2.5}$ measurements are also described.

Key words: Particulate matter, Indoor and outdoor concentrations, Automobile exhausts, Epidemiology

1. INTRODUCTION

Recently, people have become greatly concerned about particulate matter (PM) among the various ambient air pollutants. Environmental standards for PM, especially for $PM_{2.5}$ (particulate matter less than 2.5 μm in aerodynamic diameter), have been set in many countries. We have been conducting a $PM_{2.5}$ epidemiologic study and evaluating health risks of ambient $PM_{2.5}$ in Japan, and presented an outline of the study and results at an international conference (Nakai *et al.*, 2008a, b, c). However, PM sources, such as smoking, exist inside homes as well as outside, and indoor sources may contribute more than outdoor sources to personal exposure levels, because people spend a lot of time inside homes and buildings. In this paper, we briefly review the results of a personal exposure assessment of an epidemiologic study in Japan from the view point of the indoor environment and discuss the relationship between indoor and outdoor PM concentrations for PM exposure assessment. We also describe the results of other studies on indoor $PM_{2.5}$ measurements.

2. OUTLINE OF THE $PM_{2.5}$ EPIDEMIOLOGIC STUDY AND METHODS OF EXPOSURE ASSESSMENT

The Ministry of the Environment, Government of Japan, launched epidemiologic and toxicological studies to investigate the relationship between ambient $PM_{2.5}$ and its health effects. The studies started in 2001. The design of the epidemiologic study was based on the comparison of health between polluted and unpolluted areas to investigate PM's chronic effects, such as respiratory symptoms and lung function, or between days to examine acute effects, such as daily mortality and morbidity. In order to validate the study it is necessary to evaluate whether a concentration of $PM_{2.5}$ at a monitoring site is representative of personal exposure levels around the site. First, we selected a PM sampler suitable for the study, and then measured $PM_{2.5}$ personal exposure levels, and concentrations inside and outside residences.

In general, the objectives for measuring indoor and outdoor PM concentrations and for investigating the relationship between indoor and outdoor environments can be summarized as follows:

- To investigate the possibility of outdoor concentration as a personal exposure surrogate;
- To find and evaluate the modifier(s) for the health effects of ambient air pollution;
- To find specific indoor PM sources; and
- To investigate the distribution of PM concentrations among houses as well as among areas.

The subject persons/residences of $PM_{2.5}$ measurement were selected form among the non-smoking persons/houses out of the study subjects. Therefore, it would be difficult to discuss the general indoor environment in Japan from the results of this study.

Twenty-four-hour indoor and outdoor PM measurements were taken simultaneously using an impactor over seven consecutive days during each season: spring (March-May 2003), summer (June-August 2005), autumn (September-November 2004), and winter (December 2003-February 2004). Almost 20 residences without tobacco smoke from each study area (seven cities across Japan) were selected as the subjects of the indoor and outdoor measurements. A sampler for indoor measurement was set on the top of a cabinet/television in a living/children's room, and one for outdoor measurement was set under the eaves. Personal $PM_{2.5}$ and $PM_{10-2.5}$ (particles smaller than 10 μm in diameter but larger than $PM_{2.5}$) exposure levels were measured in summer and in autumn for almost ten non-smoking parents/guardians of the subject children of the cohort study in each area.

3. RESULTS OF INDOOR AND PERSONAL $PM_{2.5}$ MEASUREMENTS

The objective in the measurement design for the air-pollution epidemiologic study was mainly to compare several areas suspected of having different ambient $PM_{2.5}$ levels. The study areas were selected based on monitoring data of certain pollutants. Fig. 1 shows the study areas (areas A-G). Unfortunately for the study, but fortunately for the air environment in Japan, outdoor $PM_{2.5}$ concentration levels were not so different between the areas. The highest mean concentration from the annual means for 2001 to 2005 was around 25 μg/m^3. This is not so high (data not shown), and may reflect the fact that some pollution reduction strategies, such as the use of diesel exhaust filter equipment, have worked well.

Subject residences were distributed mostly within a 5-km radius from each monitoring site, except in area C. Area C (City C) does not have a monitoring station; therefore, data from the monitoring station in area B, which is next to area C, was used as the ambient concentration of area C. Residences in area C were almost all within a 10-km radius from the monitoring station in area B.

An ATPS-20H impactor (Sibata Scientific Technology Ltd.) was selected as a sampler for the epidemiologic study from among three types of samplers (ATPS, PEM (SKC), and Spiral (SKC)), because its two-stage filters enable the simultaneous collection of $PM_{2.5}$ and $PM_{10-2.5}$, and because it has a low-volume (1.5 L/min) and low-noise sampling, which is important for the survey inside homes, and finally because it has a lower price than the other samplers. Of course, the characteristic of particle penetration through the inlet of the ATPS-20H fits well with WINS (well impactor ninety-six; Peters *et al.*, 2001), which was designed and calibrated to serve as a particle size separation device for the EPA reference method sampler for particulate matter under 2.5 μm aerodynamic diameter (Fig. 2).

Personal exposure levels were measured during two

Fig. 1. Study area of a $PM_{2.5}$ epidemiologic study in Japan (Nakai *et al.*, 2008a).

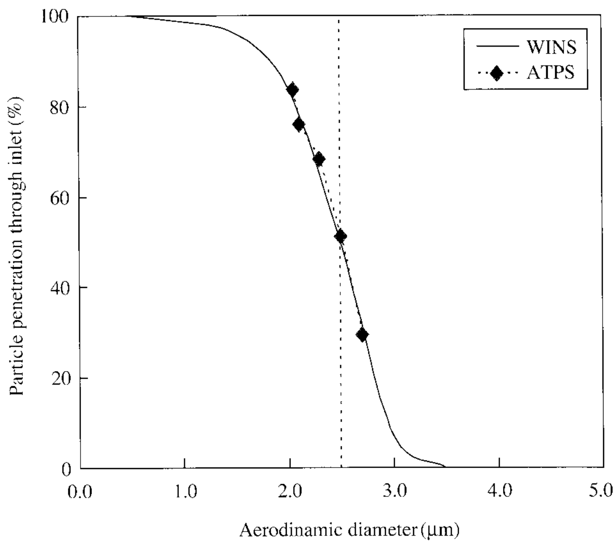


Fig. 2. Size-separation characteristics of ATPS sampler (Nakai *et al.*, 2008b).
The EPA well impactor ninety-six (WINS) was designed and calibrated to serve as a particle size separation device for the EPA reference method sampler for particulate matter under 2.5 μm aerodynamic diameter.

Table 1. Mean concentrations of $PM_{2.5}$ (Nakai *et al.*, 2008b).

Study area	Season	TEOM at ST	$PM_{2.5}$ at ST	SPM at ST	Outdoor	Indoor	Personal exposure
A	Spring (1st)	18.3	23.7	27.0	21.9	19.8	
	Winter (2nd)	19.8	32.7	28.4	31.0	22.1	
	Autumn (3rd)	29.7	41.1	49.6	43.8	34.3	37.0
	Summer (4th)	26.2	29.0	49.3	28.6	26.4	25.3
B	Spring (1st)	15.3		28.1	23.2	18.3	
	Winter (2nd)	13.1	17.6	23.6	16.9	16.7	
	Autumn (3rd)	16.6	18.6	21.7	19.9	19.7	21.6
	Summer (4th)	12.2	14.6	22.8	15.2	15.4	16.3
C	Spring (1st)	10.0		9.4	16.2	18.0	
	Winter (2nd)	15.6	20.3	13.4	21.4	16.7	
	Autumn (3rd)	11.6	15.1	13.2	14.7	15.9	17.9
	Summer (4th)	30.3	30.2	38.1	26.5	24.7	26.0
D	Spring (1st)	30.6	30.9	43.9	28.1	28.6	
	Winter (2nd)	20.9	21.0	24.7	21.2	19.7	
	Autumn (3rd)	13.2	15.5	21.0	15.5	17.4	18.8
	Summer (4th)	11.0	11.2	23.0	9.8	11.9	13.1
E	Spring (1st)	18.5	26.1	37.7	26.6	18.5	
	Winter (2nd)	13.9	17.0	27.1	17.3	15.1	
	Autumn (3rd)	23.9	26.0	47.7	26.4	25.5	25.9
	Summer (4th)	23.9	28.1	47.7	27.5	24.3	25.2
F	Spring (1st)	27.5	26.6	33.5	28.6	27.1	
	Winter (2nd)	15.8	20.1	18.8	19.6	18.4	
	Autumn (3rd)	15.8	18.1	21.4	17.4	21.1	19.4
	Summer (4th)	26.7	23.9	40.1	24.6	25.0	24.8
G	Spring (1st)	17.8	18.3	16.1	18.5	18.9	
	Winter (2nd)	11.6	11.2	5.1	12.4	17.8	
	Autumn (3rd)	12.6	13.7	10.0	14.7	17.0	18.0
	Summer (4th)	22.2	21.8	46.8	23.1	23.2	23.4

mean ($\mu g/m^3$)
ST: Monitoring station; SPM: Suspended particulate matter

measurement periods (autumn and summer). Although indoor $PM_{2.5}$ concentrations in some cities were higher than the outdoor concentrations in the autumn and winter, the concentrations outside and inside homes and personal exposure levels were similar in most areas (Table 1). For example, $PM_{2.5}$ concentrations at monitoring station A were 41.1 $\mu g/m^3$ in the autumn and 29.0 $\mu g/m^3$ in the summer; outdoor $PM_{2.5}$ levels were 43.8 $\mu g/m^3$ in the autumn and 28.6 $\mu g/m^3$ in the summer; indoor levels were 34.3 $\mu g/m^3$ in the autumn and 26.4 $\mu g/m^3$ in the summer; and personal exposure levels were 37.0 $\mu g/m^3$ in the autumn and 25.3 $\mu g/m^3$ in the summer. Daily variations in indoor concentrations and personal exposure were also similar to outdoor concentrations in all areas (Fig. 3).

It should be possible to estimate the personal $PM_{2.5}$ exposure level and indoor $PM_{2.5}$ concentrations from the outdoor $PM_{2.5}$ concentration when no PM sources exist inside a residence. But, $PM_{10-2.5}$ concentrations outside the home were lower than inside, and personal exposure levels were the highest. An indoor PM concentration that is higher than the outdoor concentration suggests that there are some unknown sources for PM inside houses, even in no-smoking houses. Unfortunately, we could not find the sources in this study. It will be necessary to find indoor PM sources and determine their contribution to indoor concentrations and personal exposure in order to improve PM pollution.

4. HEALTH EFFECTS OF PM (THE IMPACT OF INDOOR PM POLLUTION)

In PM epidemiologic studies, chronic and acute health effects of ambient PM pollution have been evaluated, and indoor pollution has been considered

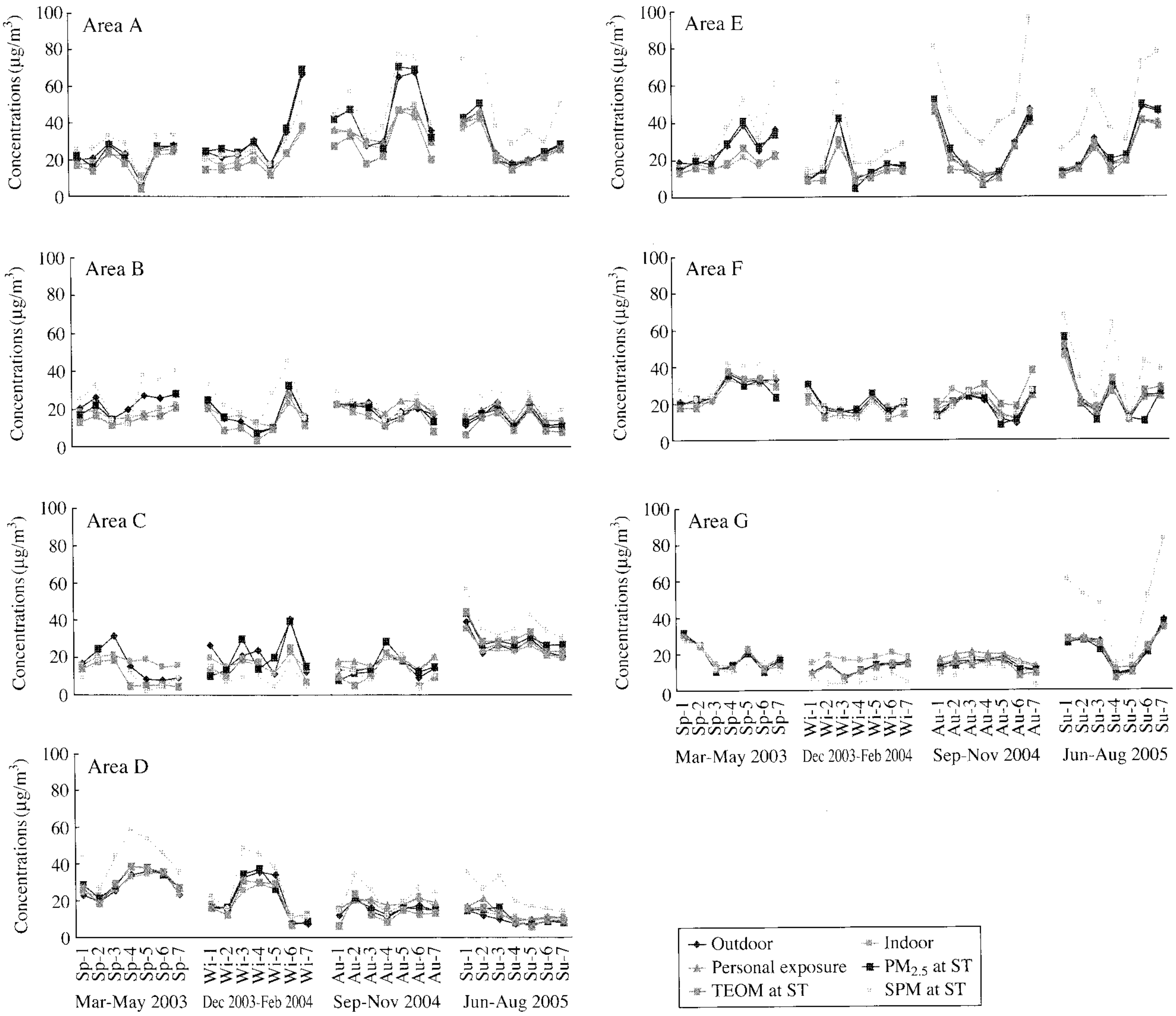


Fig. 3. Daily variation of $PM_{2.5}$ concentrations (Nakai *et al.*, 2008b).

as a confounding factor or an effect modifier in chronic health effect studies but not discussed in acute health effect studies.

Here, we would like to introduce the results of one acute health effect study (Ma *et al.*, 2008), and describe the role of indoor pollution on health. The study was conducted at a hospital in Chiba Prefecture. The relationship between the change in peak expiratory flow (PEF) and indoor and outdoor $PM_{2.5\,(LD)}$ concentrations was investigated in asthmatic inpatient children. $PM_{2.5\,(LD)}$ means $PM_{2.5}$ measured by a dust monitor with a laser diode (LD-3K, Sibata Scientific Technology Inc.). According to Ma *et al.*, the concentration of indoor $PM_{2.5\,(LD)}$ showed weak correlation with outdoor $PM_{2.5\,(LD)}$ concentration and no correlation with the concentration of stationary-site $PM_{2.5}$.

The change in PEF was significantly associated with outdoor $PM_{2.5\,(LD)}$ concentration (Ma *et al.*, 2008). However, the changes were smaller than that seen for indoor $PM_{2.5\,(LD)}$ (Fig. 5). It was concluded that the effects of indoor $PM_{2.5\,(LD)}$ were more marked than those of outdoor $PM_{2.5\,(LD)}$ or stationary-site $PM_{2.5}$. It was also revealed that the time patterns of indoor and outdoor PM concentrations were not same and that the sources of indoor PM might be different from those of outdoor PM; but, it was impossible to find any typical indoor sources, such as smoking in the hospital. Indoor PM pollution and its sources will have to be studied to clarify the effects of indoor PM on children's health.

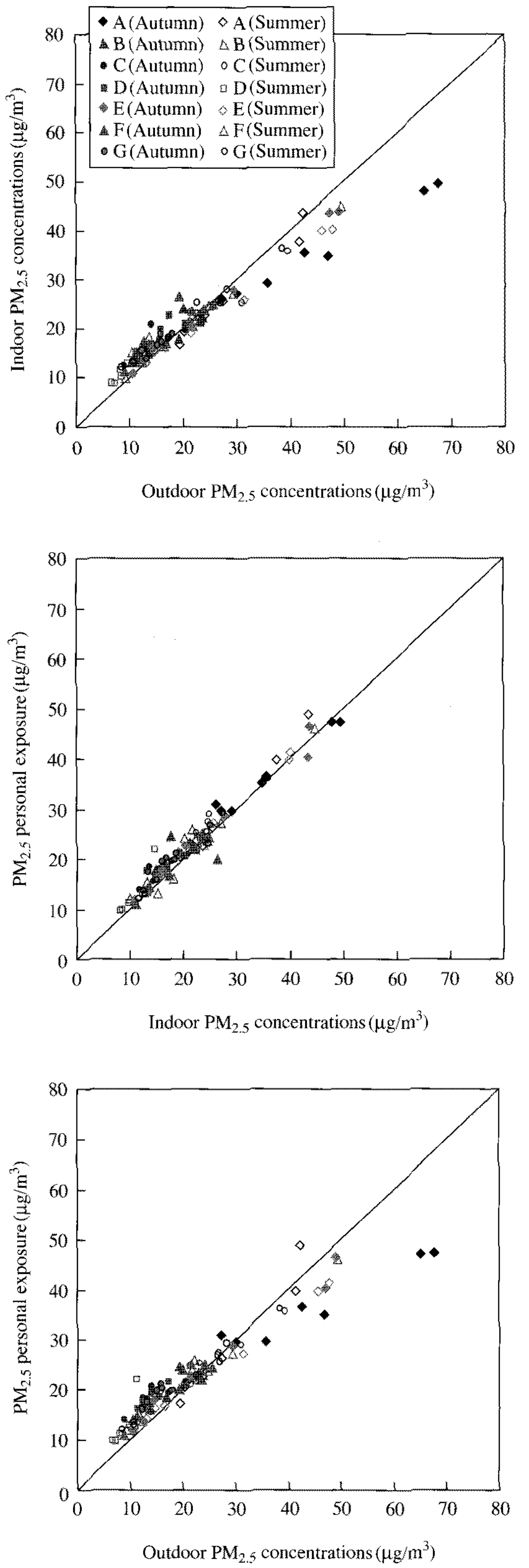


Fig. 4. Relationship between indoor and outdoor $PM_{2.5}$ concentrations and personal exposure levels (Nakai *et al.*, 2008b).

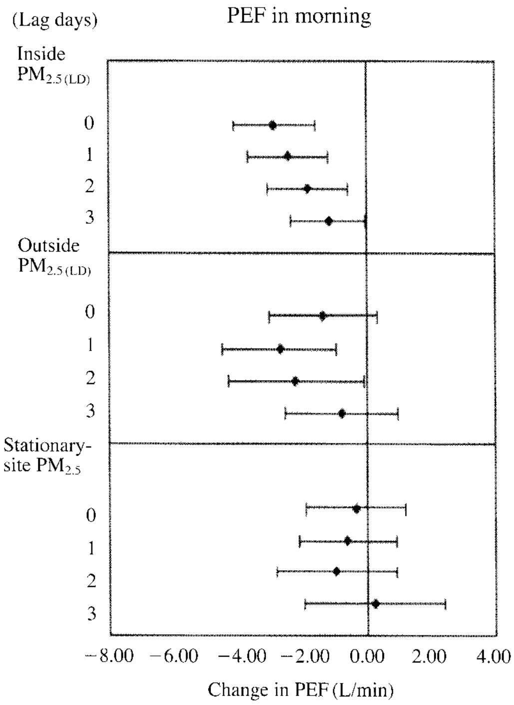
5. OTHER STUDIES RELATED TO INDOOR $PM_{2.5}$ CONCENTRATIONS IN JAPAN

People may have another concern-that is, whether indoor and outdoor $PM_{2.5}$ concentrations close to heavy traffic trunk roads are higher than at points far from the roadside. We investigated indoor $PM_{2.5}$ concentrations related to outdoor concentrations. One result is shown here, even though the study was conducted in the 1980s (Ono *et al.*, 2008). Outdoor $PM_{2.5}$ concentrations were higher than those of today. Several factors, such as automobile engines, house structure (air tightness), and the use of air-conditioners, should have changed since then. Therefore, the current situation concerning the outdoor and indoor PM environment should differ widely from the reported results from the 1980s. In general, outdoor $PM_{2.5}$ and PM_{10} concentrations were higher in roadside areas than backyards. However, the concentrations of $PM_{2.5}$ and PM_{10} in smokers' houses were significantly higher than those in non-smokers' houses (Ono *et al.*, 2008), and the contribution of smoking to indoor $PM_{2.5}$ concentrations was bigger than that of the outdoor air due to automobile exhaust (Fig. 6). It was also reported that approximately 50-80% of the indoor $PM_{2.5}$ mass was associated with cigarette smoke in winter, and the contribution of tobacco in summer was 70-80% based on a receptor model, although the contribution varied among the data sets (Nitta *et al.*, 1994).

Particulate matter mentioned in this paper was related to outdoor PM sources, mainly automobile exhaust. We would like to show another type of PM pollution, namely bio-aerosol. We investigated the longitudinal change of airborne mite-allergen levels in one home, although the relationship between indoor and outdoor was not considered. Fig. 7 shows weekly indoor mite allergen levels. The highest mite allergen level (Der 1) in the living room was 25.7 pg/m^3 during November, and the highest monthly PM_{10} level was observed during October. However, no relationship was observed between the weekly mean level of indoor airborne mite allergen (Der 1) and indoor PM_{10} (Nakai *et al.*, 1999). Seasonal changes of clothes and bedding, which might be different factors from the ones for $PM_{2.5}$ and PM_{10} pollution, should be considered to investigate bio-aerosol pollution.

6. CONCLUSION

In this paper, we tried to describe indoor PM pollu-



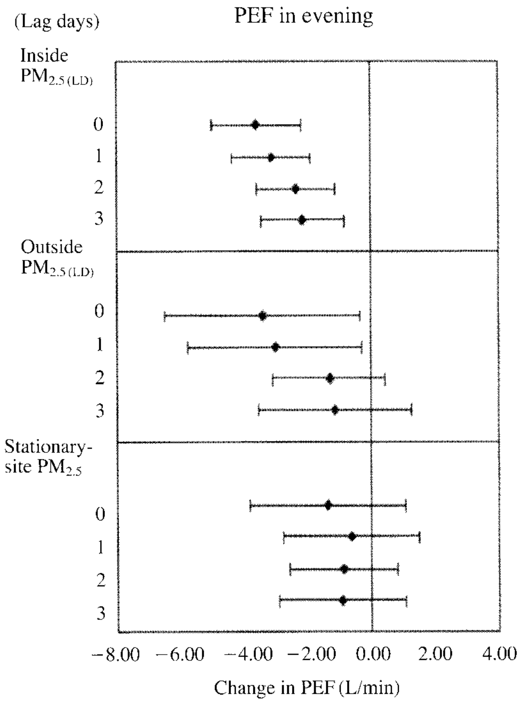


Fig. 5. Changes in peak expiratory flow (PEF) in relation to the concentration of $PM_{2.5}$ for every 24-hour period up to 3 days before the measurement (Ma *et al.*, 2008).

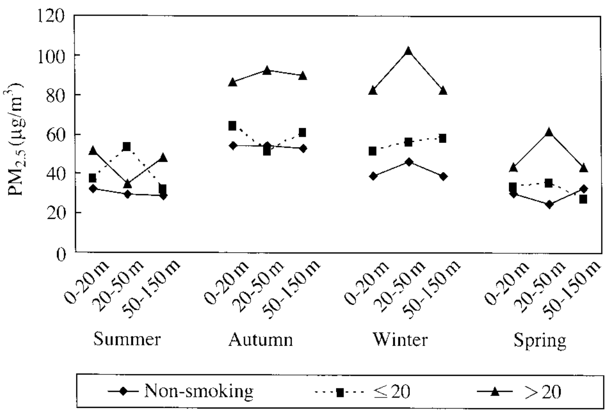


Fig. 6. Indoor $PM_{2.5}$ levels stratified by zone from the road-side and smoking residences (from Ono, 1989; Nakai, 2003; and Ono, 2008)

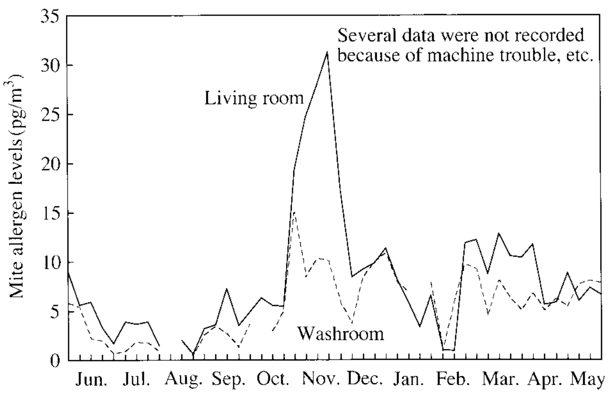


Fig. 7. Weekly indoor airborne mite allergen levels (Der 1) (Nakai *et al.*, 1999)

tion from the view of the relationship between indoor and outdoor pollution, because people spend more time indoors than outdoors. However, they also spend time outdoors, and so outdoor PM pollution should remain a main concern in general. It was revealed that outdoor PM pollution contributes to personal exposure in the case of no PM sources inside homes. However, the contribution of indoor sources on indoor air pollution is high, and in some cases higher than outdoor sources. The health effects of indoor PM are not yet clear, although PEF among asthmatic impatient children was affected by indoor PM. The relationship between indoor PM and other pollutants, such as other combustion products, and biological contaminants has to be considered to evaluate their health effects.

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