보건학석사 학위논문

Evaluation of Personal Exposure to Particulate Matter During Winter in Ulaanbaatar, Mongolia

몽골 울란바타르에서 겨울철 입자상 물질의
개인노출 평가

2019 년 8 월

서울대학교 보건대학원
환경보건학과 환경보건학 전공

신 혜 린

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이 논문을 보건학석사 학위논문으로 제출함

2019년 5월

서울대학교 보건대학원

환경보건학과 환경보건 전공

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신 혜 린의 보건학석사 학위논문을 인준함

2019년 7월

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Abstract

Evaluation of Personal Exposure to Particulate Matter During Winter in Ulaanbaatar, Mongolia

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Ulaanbaatar, the capital city of Mongolia has a serious air pollution during winter. Residents of ger, Mongolian traditional housing structure, used coal as indoor heating and cooking fuel. $PM_{2.5}$ is one of the main air pollutants in coal combustion. It was critical to characterize personal exposure to $PM_{2.5}$ to prevent adverse health effects by indoor coal burning. This study was conducted to compare personal exposure to $PM_{2.5}$ of ger and apartment residents by residential characteristics and to evaluate the influence of time-activity patterns on personal exposure to $PM_{2.5}$. Two-day personal exposures of 16 couples in ger and 16 couples in apartments in Ulaanbaatar, Mongolia were measured from January to February, 2019. All 32 couples were consisted of a full-time working husband and a homemaking housewife. Aslung monitor (Rododo Science, Taiwan) was used for measuring $PM_{2.5}$. Co-location tests were performed to calibrate the data measured by Aslung with gravimetric methods. To record the time-activity patterns, participants were asked to write the logbook. Microenvironment was divided into home, workplace, outdoor, transportation, and other indoors. Face-to-face surveys were conducted to investigate housing characteristics. The geometric mean of personal exposure to $PM_{2.5}$ of ger residents was 59.1(1.7) $\mu g/m^3$ which was significantly higher than that of apartment residents of 26.8(2.0) $\mu g/m^3$ (p<0.001). Personal exposure increased in the morning when people started activity, decreased in the afternoon, and increased again in the evening regardless of housing type. Similar to indoor air pollution, the ambient $PM_{2.5}$ concentration was maximum at 10:00 and minimum at 17:00. $PM_{2.5}$ concentrations at all microenvironment were higher in ger residents. A linear regression analysis identified housing type and ambient $PM_{2.5}$ concentration as significant factors affecting hourly personal exposure (p<0.001). Exposure at home had the highest contribution to 24-hour personal exposure to $PM_{2.5}$. The $PM_{2.5}/PM_{10}$ ratio was ranged from 0.73 – 0.96 in all microenvironment. This study found that ger residents were exposed to higher $PM_{2.5}$ concentration than apartment residents by indoor coal burning. Reducing measures considering ambient $PM_{2.5}$ concentration are required to prevent residents of Ulaanbaatar from adverse health effects of $PM_{2.5}$ emitted by coal combustion.

Keywords: Personal exposure, Particulate matter, Time-activity pattern, Exposure assessment, Microenvironment, $PM_{2.5}$

Student Number: 2017-28248

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I. Introduction

Ulaanbaatar, the capital city of Mongolia has a serious air pollution problem during winter season. In Ulaanbaatar, temperatures reached -20 degrees Celsius in winter, and heating was required for about nine months a year (Lee et al., 2016). Coal-fired power plants were operated for heating during winter, and this contributed to severe particulate matter with aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$) pollution (Amarsaikhan et al., 2014). During winter time (December to February), the average $PM_{2.5}$ concentration in Ulaanbaatar was 147.8 ± 61.2 μg/m^3 while 22.8 ± 9 μg/m^3 during summer (June to August) (Allen et al., 2013). Rapid urbanization along with industrialization and increased public and private transportation also intensified air pollution in Ulaanbaatar (Davy et al., 2011).

Such air pollution was associated with various health effects. Forty percent (95% CI, 17-56%) of lung cancer deaths and 29% (12-43%) of cardiopulmonary deaths in Ulaanbaatar were attributable to outdoor air pollution in Ulaanbaatar (Allen et al., 2013). Seasonal ambient air pollutants and spontaneous abortion had strong statistical correlations in Mongolia (Enkhmaa et al., 2014). The prevalence of asthma in Mongolian children was higher than in other countries in Asia-Pacific, and severe air pollution was found to be associated (Yoshihara et al., 2016).

Majority of Ulaanbaatar's population lived in a Ger, traditional residence of Mongolia, and they used coal as indoor heating and cooking fuel (Guttikunda, 2007). Ger is studio-type space without the distinction of a bedroom and a kitchen, with stove and chimney in the center. Ger residents used direct burning of solid fuel like coal in the central stove. Therefore, ger residents are highly exposed to pollutants caused using coal indoor in the winter. In a previous study, the $PM_{2.5}$ concentration inside the ger was higher than the $PM_{2.5}$ concentration inside the apartment (Enkhbat et al., 2016).

In many developing countries including Mongolia, people used solid fuel as indoor heating and cooking fuel. One-third of the world's population used organic material like wood, coal, or feces as fuel for cooking, heating, and lighting (Fullerton et al., 2008). According to the WHO report, 77% of Africa, 16% of South America, 16% of Central and Eastern Europe, 74% of Southeast Asia, and 74% of Western Pacific sill used biomass as household fuel (WHO. 2000). WHO guidelines recommended that biomass not be used as household fuel, however developing countries continue to use biomass indoors for reasons as economic conditions.

Indoor biomass burning caused various adverse health effects. Lung cancer mortality rate was five times the national average and it revealed that it was caused by indoor coal use in rural Xuan Wei county, China (Lan et al., 2000). Exposure to pollutants from indoor biomass fuel was leading cause of Acute Respiratory Infections (ARI) (Ezzati and Kammen, 2001). Domestic coal smoke was also associated with Chronic Obstructive Pulmonary Disease

(COPD) (Hosgood et al., 2009). Pollution from indoor coal use impaired early childhood skeletal growth to age 36 months (Ghosh et al., 2011).

$PM_{2.5}$ was one of the main pollutants in solid fuel smoke (Hu et al., 2014). Indoor $PM_{2.5}$ concentration in the household using only biomass was higher than that of household using kerosene or gas as fuel in Southern India (Balakrishnan et al., 2002). Biomass burning for cooking indoor increased the indoor $PM_{2.5}$ concentration and contributed exposure to residents in Northestern China (Jiang and Bell, 2008). It was observed that biomass fuel occupied a major portion of the indoor $PM_{2.5}$ source in Bangladesh (Begum et al., 2009). In cities, indoor $PM_{2.5}$ concentration increased significantly when burning biomass for heating in Greece (Sarigiannis et al., 2014).

It is necessary to characterize personal exposure to $PM_{2.5}$ to prevent adverse health effects by $PM_{2.5}$ emitted by indoor coal burning. In previous study conducted in Mongolia, the average indoor $PM_{2.5}$ concentration in ger ranged from 69.4 ± 47.3 to 202.7 ± 228.8 $\mu g/m^3$ (Lee et al., 2016). In a study conducted in 2018, the average indoor $PM_{2.5}$ concentration of ger ranged from 64.6 ± 31.0 to 269.0 ± 142.8 $\mu g/m^3$, and outdoor concentration had absolute influence (Ahn et al., 2019). However, these studies measured indoor $PM_{2.5}$ concentration of ger and have limitations in assessing personal exposure.

Using $PM_{2.5}$ concentration at each microenvironment and individual time-activity diary data, personal exposure in various microenvironments could be obtained (Baxter et al., 2013). Exposure to $PM_{2.5}$ could increase depending on the microenvironment and activity in which the individual stays (Rea et al., 2001). A personal exposure study of couples living in a single home showed that women were exposed to high PM concentration in both summer and winter than men (Buonanno et al., 2014). Microenvironment (e.g. indoor, outdoor, and transportation) and indoor activities (e.g. eating, sleeping, and general activity) also contributed to the individual's daily personal exposure (Lei et al., 2016).

Microenvironmental $PM_{2.5}$ concentration could be obtained through personal sampling using user-friendly device (Banhazi, 2009). To measure personal exposure to PM, user-friendly device such as real-time low-cost sensors were able to be used (Koehler and Peters, 2015; Steinle et al., 2015; Patel et al., 2017). Many studies were conducted to demonstrate low-cost sensors' reliability (Austin et al., 2015; Gao et al., 2015; Wang et al., 2015). Personal monitoring with small and battery-powered instruments were used to measure individual's exposure in a variety of microenvironments (Steinle et al., 2015). A low-cost wireless PM sensor network was developed and used to measure indoor PM concentration in households using solid fuel (Patel et al., 2017).

Personal exposure to PM was strongly related to the time-activity patterns (Buonanno et al., 2011, 2012). Even if a couple lived in a single home, personal exposure could vary depending on the individual's time-activity pattern (Buonanno et al., 2014). For exposure assessment to environmental pollutants, many countries conducted time-activity pattern studies (Leech et al., 2002; Lee and Lee, 2017; Matz et al., 2014). According to the results of the National Human Activity Pattern Survey (NHAPS) in the United States, exposure to environmental tobacco smoke (ETS) varied across regions depending on time-activity patterns (Klepeis et al., 2001). The results of EXPOLIS, European research project on exposure research and environmental policy, also showed that individuals were exposed to ETS according to time-activity patterns (Schweizer et al., 2007).

The purposes of this study were (1) to compare personal exposure to $PM_{2.5}$ of ger and apartment residents by residential characteristics in Ulaanbaatar, Mongolia. (2) to evaluate the influence of time-activity patterns on personal exposures to $PM_{2.5}$.

II. Materials and Methods

2.1 Study design

This study was conducted on 16 couples of ger and 16 couples of apartments in Ulaanbaatar, Mongolia from January to February 2019. Measurements were conducted on weekdays to perform their daily routines. The week including the Lunar New Year was excluded from the sampling schedule. All 32 couples were all non-smokers and consisted of a full-time working husband and a homemaking housewife. This was a setting to identify differences in personal exposure according to time-activity patterns. The age of the participant was older than 20 years and there was no limitation on the maximum age.

Participants were asked to carry measuring equipment for a total of 48 hours, starting on the same date and time for each couple. They were asked to write logbooks in order to identify the microenvironment (Home, Workplace, Outdoor, Car/Bus, and Other indoors) that they visited, and record behavioral information such as adding fuel, cooking, and passive smoking. Records of the microenvironment were made every 30 minutes. Researchers created questionnaire to investigate housing characteristics and demographic information of participants and conducted a face-to-face survey when they visited for measurements.

2.2 Equipment

Aslung monitor (Rododo Science, Taiwan) was used for this study (Figure 1). The device could measure temperature, relative humidity, and PM (PM_1, $PM_{2.5}$, PM_{10}) concentration. Aslung monitor included a GPS module, which allowed the location of research participants during their sampling period. Aslung monitor was a real-time device using a light-scattering type sensor for PM. Aslung contained three sensors in total, and the sensors measured temperature, relative humidity, PM, and CO_2 concentration. One PM sensor can measure PM_1, $PM_{2.5}$, and PM_{10} simultaneously.

After the air was introduced into Aslung through a small fan, they passed through the illumination area of the light scattering sensor. The amount of scattered light was measured as the number concentration of PM ($\#/m^3$) by light scattering method and converted it to mass concentration ($\mu g/m^3$). Data was stored every 15 seconds in SD card inserted in Aslung. To supply power, connection with the charged secondary battery was required, since it did not have the function of battery charging. Before every measurement, the date and time were set by connecting to the configuration Human- Machine Interface (HMI).

Figure 1. Low-cost sensor used in this study
(Aslung, Rododo Science, Taiwan)

2.3 Time-activity pattern

To record the information of microenvironment where and how long participants stayed, they were asked to write the logbook for time-activity patterns at every 30 minutes during 48 hours. The microenvironment was divided into home, workplace, outdoor, car/bus, and other indoors. Participants were asked to check up to two microenvironment in 30 minutes interval if they stayed more than one microenvironment during that time. Participants marked if there was fuel addition, cooking, and passive smoking in each time interval. The entire logbook was included in appendix 1. Logbook written in English was translated into Mongolian for the convenience of participants and delivered.

2.4 Questionnaire

Face-to-face surveys were conducted to investigate housing characteristics and demographic information. The questionnaire was composed as follows; (1) Fundamental information: sex, age, address, occupation, and contact information. (2) Demographic characteristics: height, weight, education level, monthly income, and current job position. (3) Lifestyles: smoking habits in the past, drinking habits, the average time of sleeping, the number of taking shower per week, the number of washing hands per day, and the number of brushing teeth per day. (4) Living environment: how long they live in current house, when the house was built, type of heating and cooking fuel, and whether pets are raised. (5) Outdoor environment: road and environment facility near house. (6) Current health status: whether they are diagnosed or symptomatic acute diseases, whether they are taking medical measures for those diseases. The entire questionnaire was included in appendix 2. Questionnaire written in English was translated into Mongolian for the convenience of participants and delivered. Since the questionnaire contained personal information, it was conducted after receiving the IRB approval from Mongolian National University of Medicine (IRB #2019/3-01).

2.5 Quality assurance

Since Aslung detected real-time concentration of PM using light-scattering sensor, it needed calibration with gravimetric method. For the calibration, 44 consecutive co-location tests of the average $PM_{2.5}$ concentration obtained by gravimetric method and light-scattering method through Aslung over 6 hours were conducted in ger (*N*=12) and modern buildings (*N*=5) in Mongolia.

The $PM_{2.5}$ samples were collected on Zeflour filters (with a 37-mm diameter and a 2.0-um pore size, supported by polytetrafluoroethylene [PTFE]; Pall Life Science, USA). PTFE filter was placed inside the PEM (SKC Inc., USA) and connected to the pump (BUCK Libra™ L-4 Pump) to deposit $PM_{2.5}$. The flow rate of the pump was 4 L/min and measured by Bios Drycal Defender 530 calibrator (Mesa Laboratories, USA) before and after the measurement. Mettler Toledo XP2U Microbalance (Mettler Toledo, Switzerland) was used to weigh deposited $PM_{2.5}$ in PTFE filters at a constant temperature and humidity room before and after the measurement.

The results of co-location test was shown in figure 2. The x-axis was the average concentration of Aslung during test time and the y-axis was the concentration obtained by gravimetric method. The slope of the regression equation of the result was 0.4731, which was used as the correction factor of the data from Aslung. R^2 was 0.7822.

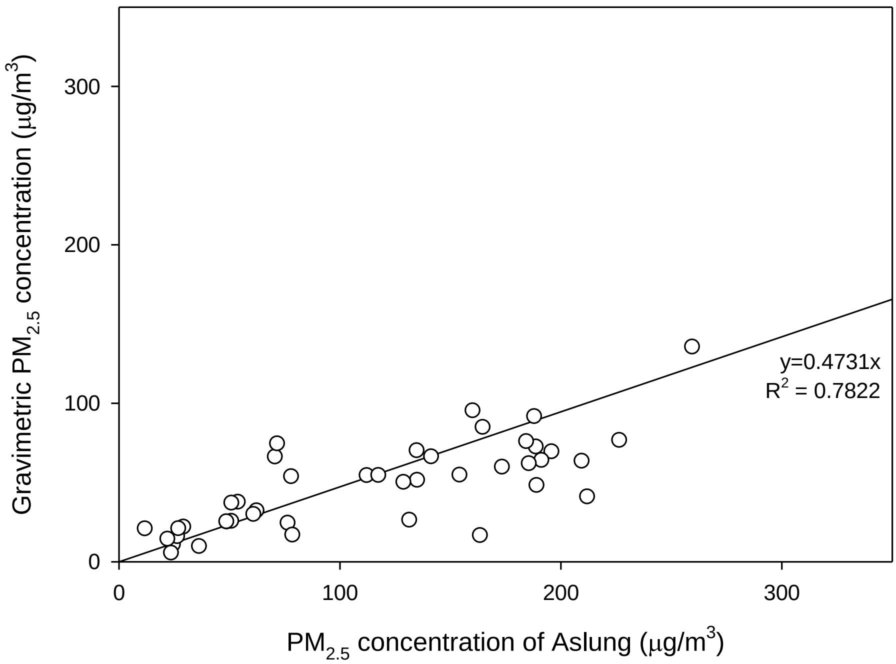

Figure 2. Result of 44 co-location tests with light-scattering method from Aslung and gravimetric method in Ulaanbaatar, Mongolia

2.6 Data analysis

All statistical analysis was conducted by R-software (R Development Core Team, Vienna, Austria). Graphs were drawn in SigmaPlot 10.0 (Systat Software INC., Chicago, IL, USA). Microsoft Azure Machine Learning Studio (Microsoft Azure, Seattle, USA) was used for *k*-means clustering.

Data collected at intervals of 15 seconds through Aslung were converted to 1 minute average concentration and used as basic data. The descriptive statistics of the demographic information and the residential characteristics of the residential environment of each household were indicated. Student's *t*-test was conducted to determine the differences in 24-hour personal exposure to $PM_{2.5}$ between ger and apartment residences, and couples. *K*-means clustering analysis was used to cluster the two-day $PM_{2.5}$ concentration profiles of 64 research participants. A linear regression analysis was conducted to confirm the relationship between personal exposure to $PM_{2.5}$ and the factors such as housing type, couples, and each microenvironment, respectively. This model considered random effects of each household. A p-value<0.05 was considered statistically significant.

III. Results

3.1 Housing characteristics

Table 1 showed housing characteristics of ger and apartment. All of the ger households heated their home individually by using stoves. Ger residents used coal and wood as heating fuel. In contrast, 12 of 16 apartment households had central heating system. All of ger households used coal as heating fuel, and 15 households used wood together. Twelve households used coal and wood together for cooking. Two of ger households cooked using electronic induction. On the other hand, all apartment households used electricity as heating and cooking fuel. Apartment residents cooked using induction. The power from the coal power plant was used as an energy source. All of ger households had toilet outdoor, and all of apartment households had toilet in their house. For ger households, there was no separation between kitchen and living space for all households. In contrast, all kitchens of apartments were separated from the living room or dining room.

Table 2 indicated the behavior characteristics of cooking, ventilation, and cleaning habits of the ger and apartment residents. The number of cooking of apartment residents was higher than that of ger residents. Twelve point five-percent of ger residents and 37.5% of apartment residents cooked more than 3 times a day on average. Apartment residents ventilated their house more often than ger residents. Thirty one point three-percent of ger residents had almost no ventilation during the day, and 56.3% of them ventilated their home once or twice a day. Ninety three point eight-percent of apartment residents had ventilation once or twice a day. Fifteen of 16 ger households had no air purifiers. On the other hand, there were 15 households with air purifiers among the 16 apartment households. Eighty-seven point five percent of both of ger and apartment households cleaned their home daily. Most of the ger and apartment households cleaned their home using brooms or water cleaning. Vacuum cleaners were used in 1 ger household and 4 apartment households.

Table 2. Housing characteristics of ger and apartment

Variable	Ger	Apartment
Heating		
Self-controlled	16	4
Central-controlled	0	12
Fuel type – heating		
Coal	1	0
Coal+Wood	15	0
Electricity	0	16
Fuel type - cooking		
Coal	2	0
Coal+Wood	14	0
Electricity	2	16
House built year		
After 2010	9	8
2000~2009	4	4
1990~1999	0	2
Before 1989	3	2

Table 3. Behavior characteristics of cooking, ventilation, and cleaning of ger and apartment

Variable	Ger	Apartment
Number of cooking		
Once a day	3	0
Twice a day	11	10
Three times a day or more	2	6
Number of ventilation		
Almost not	5	1
1~2 times a day	9	15
3 times a day or more	2	0
Air purifier		
Owning	1	15
Not-owning	15	1
How to ventilate home		
Window opening	0	14
Roof opening	10	0
Operating air purifier	1	15
None	5	0
Number of cleaning		
1~2 times a week	0	2
3~4 times a week	1	0
5~6 times a week	1	0
Everyday	14	14
How to clean home		
Using a vacuum cleaner	1	4
Using a broom	15	12
Water cleaning	15	15

3.2 Demographic information

The demographic information of participants was indicated at table 3. The age of research participants ranged from 20 to 59 years, and the both of participants who live in ger and apartment were the most frequent in 30s. For the job position, most of the participants were the regular workers who were contracted for one year or more. Among the participants, there were police officer, doctor, and carpenter. Ger residents had the highest number of degrees in high school diplomas, while those in apartment residents had the highest degree in undergraduate degrees. The monthly income of 62.5% of the ger residents was below 1,000 dollars, and 56.3% of apartment residents had income over 4,000 dollars per month.

The results of information of health-related behabiors of research participants were presented in table 4. The sleeping time was most frequent in 8-9 hours per day regardless of housing type. All of the number of taking a shower per week, the number of washing hands per day, and the number of brushing teeth were higher in apartment residents than ger residents. Most of the ger residents responded they took a shower once or twice a week, followed by 3-4 times a week. Apartment residents also had the largest respondents who took a shower once or twice a week, but respondents for 3-4 times per week were 5 times more than the ger residents.

Table 4. Demographic information of ger and apartment residents

Variable		Ger	Apartment
Age	20-29	7	7
	30-39	15	11
	40-49	6	10
	50-59	4	4
Job position (Men only)	Self-employed	5	3
	Regular worker	11	13
Education level	Degree below high school	6	5
	High school diploma	14	8
	Undergraduate degree	12	18
	Graduate school or higher	0	1
Household income	Below 1,000 dollars	20	2
	1,000 to 2,000 dollars	12	12
	2,000 to 4,000 dollars	0	10
	Over 4,000 dollars	0	18

Table 5. Health-related behaviors of ger and apartment residents (unit: %)

Variable		Ger	Apartment
Sleeping time (per day)	Less than 5 hours	6.3	3.1
	6-7 hours	37.5	40.6
	8-9 hours	46.9	53.1
	Over 10 hours	9.4	3.1
Number of taking showers (per week)	Never	0.0	0.0
	Once or twice	93.8	56.3
	3-4 times	6.3	34.4
	5-6 times	0.0	9.4
Number of washing hands (per day)	Less than 3 times	28.1	9.4
	3-10 times	62.5	53.1
	Over 10 times	9.4	37.5
Number of brushing teeth (per day)	Never	3.1	0.0
	Once	40.6	18.8
	Twice	56.3	75.0
	Over 3 times	0.0	6.3

3.3 Personal exposure to $PM_{2.5}$

24-hour personal exposure to $PM_{2.5}$

Table 5 showed 24-hour personal exposure to $PM_{2.5}$ by housing type and couple. Difference in personal exposure to $PM_{2.5}$ by housing type (ger and apartment) was indicated in figure 3. The distributions of personal exposure of 4 groups were geometric distribution. The geometric means of personal exposure to $PM_{2.5}$ were 59.1(1.7) $\mu g/m^3$ and 26.8(2.0) $\mu g/m^3$ for ger and apartment residents, respectively. Personal exposures to $PM_{2.5}$ of 4 groups were 57.8(1.7), 60.5(1.6), 28.5(1.9), and 25.2(2.0) $\mu g/m^3$. There was a statistically significant difference in personal exposure to $PM_{2.5}$ between ger and apartment residents ($p<0.001$).

Figure 4 showed correlation between husband and wife of 24-hour personal exposure to $PM_{2.5}$. There was a strong correlation between the couples. The slope was 0.8772 and the R^2 was 0.7579 when the x-axis as personal exposure to $PM_{2.5}$ of husband were plotted with y-axis as personal exposure to $PM_{2.5}$ of wife. Households with high personal exposure to $PM_{2.5}$ of their husband also showed higher personal exposure to their wife. There was no statistically significant difference in personal exposure to $PM_{2.5}$ between husband and wife.

Table 6. Descriptive statistics of 24-hour personal exposure to $PM_{2.5}$ by housing type and couple

Housing type	Couple	Personal exposure to $PM_{2.5}$ (μg/m^3)					
		GM (GSD)	Min	25th	50th	75th	Max
Ger	Husband	57.8 (1.7)	21.4	41.0	57.4	84.0	188.9
	Wife	60.5 (1.6)	23.1	40.0	62.6	81.5	183.9
	All	59.1 (1.7)	21.4	40.2	62.6	83.2	188.9
Apartment	Husband	28.5 (1.9)	6.3	17.8	28.5	44.4	97.6
	Wife	25.2 (2.0)	6.3	15.0	27.2	38.2	81.7
	All	26.8 (2.0)*	6.3	17.0	27.4	39.3	97.6

* $p<0.001$

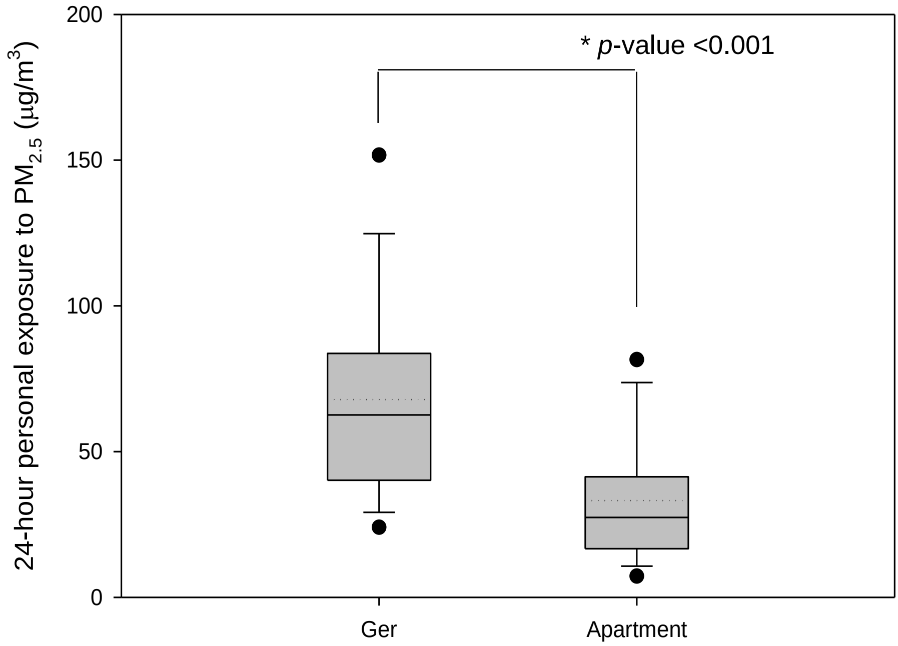

Figure 3. Boxplots of 24-hour personal exposure to $PM_{2.5}$ by housing type (The top line of the box is 75 percentile value, and the bottom line is 25 percentile value. The middle line is the median value, and the dotted line is the mean. The vertical lines above and below the box represent 5 percentile value and 95 percentile value)

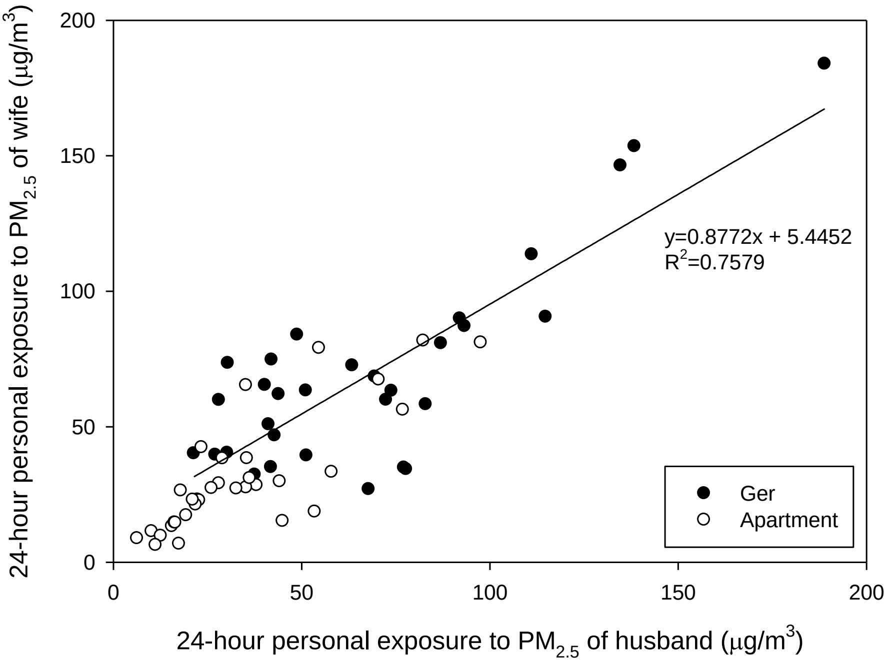

Figure 4. Correlation between husband and wife of 24-hour personal exposure to $PM_{2.5}$

Hourly personal exposure to $PM_{2.5}$

Hourly variations of personal exposure to $PM_{2.5}$ in 4 groups were shown in figure 5. All 4 groups showed decreases in personal exposure at dawn and sharp increases in the morning hours. Personal exposure decreased in the afternoon and showed an increasing patterns in the evening. Personal exposure to $PM_{2.5}$ was high in ger residents, except at dawn time. Both ger and apartment residents showed similar patterns of variation of hourly personal exposure to $PM_{2.5}$ between couples.

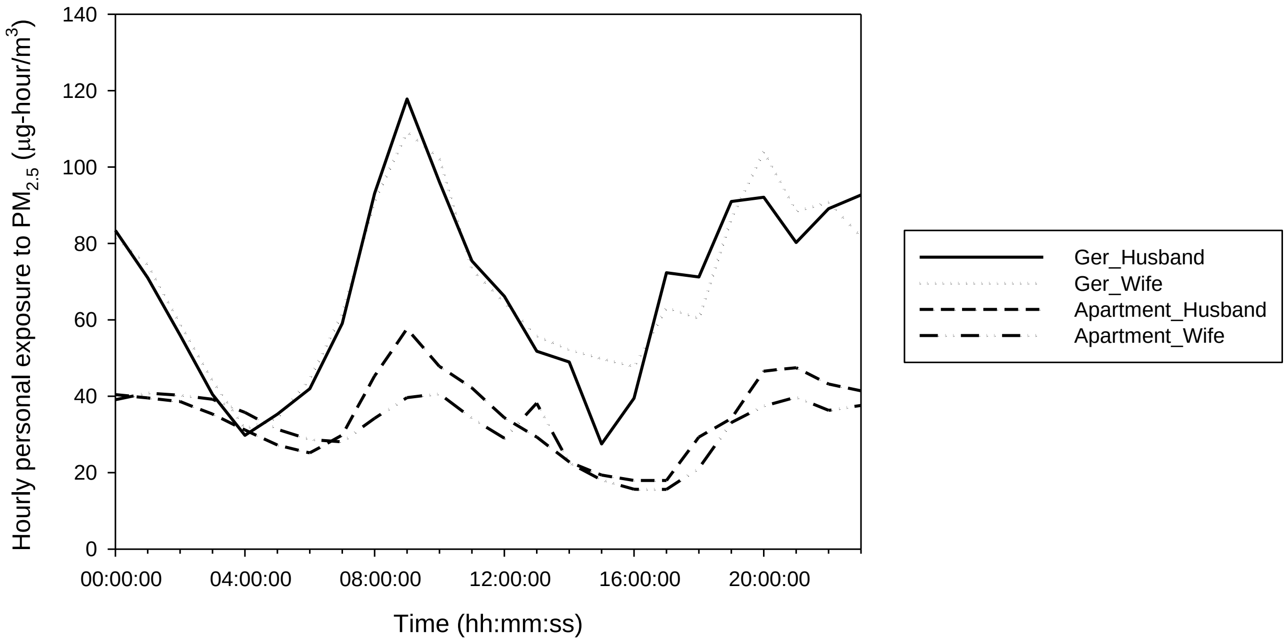

Figure 5. Variations of hourly personal exposure to $PM_{2.5}$ of 4 groups

K-means clustering

Twenty four-hour real-time profiles of personal exposure to $PM_{2.5}$ of research participants were divided into 6 clusters through *k*-means clustering and shown in figure 6. The $PM_{2.5}$ concentration was standardized to the minimum value of 0 and the maximum value of 100 for the $PM_{2.5}$ concentration in which the individual was exposed for 24-hour. Most of the profiles of 6 clusters showed that personal exposure increased in the morning hours, the decreased concentration in the afternoon hours, and rose again in the evening.

Cluster 0 showed a gradual decline while maintaining a high concentration at dawn, then increased again at the morning and increased again at around 17:00. Cluster 1 showed low concentration at dawn, increased at morning, decreased in the afternoon and showed maximum concentration at evening. In cluster 2, the concentration decreased from 0:00 to 5:00 and then increased in the morning. The sudden decrease in the concentration at afternoon showed an upward trend in the evening and remained at a similar level. Cluster 3 showed the maximum concentration from 22:00 to 0:00 during 24 hours and then decreased rapidly at dawn, and peaked at 14:00. The profile, which showed an upward trend since 16:00, showed a peak again at 0:00. Cluster 4 showed rapid increase from 6:00 and peaked at 11:00. The decreased concentration remained at similar levels from 14:00 to 18:00 and then rose in the evening. Cluster 5 showed the lowest concentration among 6 clusters from 0:00 to 4:00, and peaked at 8:00 with increasing concentration from 5:00. The concentration decreased until 10:00 and rose again to reach its maximum at 13:00.

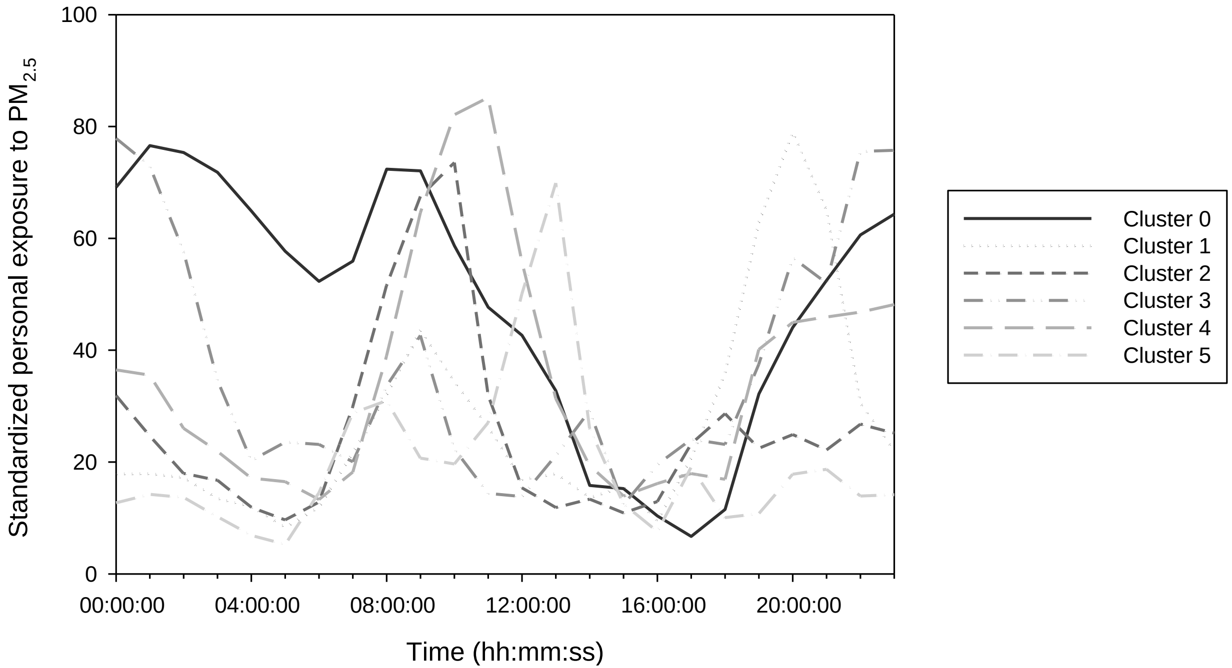

Figure 6. Real-time personal exposure to $PM_{2.5}$ of 6 clusters by *k*-means clustering

Linear regression analysis

A linear regression analysis was conducted to determine the relationship between hourly personal exposure to $PM_{2.5}$ and factors such as housing type, couple, each microenvironment, and the ambient $PM_{2.5}$ concentration (table 6). As a result of the linear regression analysis, housing type and the ambient $PM_{2.5}$ concentration were significant factors to personal exposure ($p<0.001$). This study did not reveal statistically significant differences between the couples and microenvironment.

Table 7. Results of linear regression analysis of hourly personal exposure to $PM_{2.5}$

Variable	**Estimate**	**Std.Error**[1)]	***t*-value**	***p*-value**
(Intercept)	16.53	2.46	6.71	<0.001
Housing type	36.79	1.99	18.52	<0.001
Couple	1.55	2.23	0.70	0.49
Home	-	-	-	-
Workplace	5.31	2.94	1.81	0.07
Outdoor	5.4	6.69	0.81	0.42
Car/Bus	-11.33	6.63	-1.71	0.09
Other indoor	-8.02	9.15	-0.88	0.38
Ambient $PM_{2.5}$ concentration	0.09	0.01	12.95	<0.001

[1)] Std.Error; Standard error [2)] Adjusted R-squated; 0.15

3.4 Microenvironmental $PM_{2.5}$ concentration

Table 7 indicated descriptive statistics of the $PM_{2.5}$ concentration in each microenvironment of ger and apartment. Figure 7 - 10 showed the variations of microenvironmental $PM_{2.5}$ concentration by 1 hour for 24 hours by housing type. (a) is the result of ger and (b) is the result of apartment. Each bar represented $PM_{2.5}$ concentration at the interval of 1 hour. The top line of the box is 75 percentile value, and the bottom line is 25 percentile value. The middle line is the median value, and the dotted line is the mean. Vertical lines above and below the box represent 5 percentile value and 95 percentile value, respectively.

The variation of $PM_{2.5}$ concentration at home of ger and apartment was shown in figure 7. Both housing type had low $PM_{2.5}$ concentrations at dawn and increased concentrations in the morning when people started to work. The concentration increased in the evening. Concentration of ger was higher than that of apartment, and the variation was also larger than apartment. This showed ger residents were exposed at higher level of $PM_{2.5}$ at home than apartment residents.

Figure 8 indicated the variation of $PM_{2.5}$ concentration in the husbands' workplace of ger and apartment. The rate of night workers among ger residents was higher than that of apartment residents, indicating that $PM_{2.5}$ concentration was measured at work even at dawn time. In contrast, apartment residents had a higher percentage of office workers who worked from 9:00 to 18:00. $PM_{2.5}$ concentration and variation in the workplace were also higher in ger residents.

Variation of outdoor $PM_{2.5}$ concentration of ger and apartment residents was represented in figure 9. In contrast to apartment, the number of ger residents who went out at dawn was larger. Outdoor $PM_{2.5}$ concentrations also increased in the morning and again decreased during afternoon, and increased in the evening. The $PM_{2.5}$ concentrations exposed at outdoors by ger residents were higher than those of the apartment residents.

Figure 10 showed hourly $PM_{2.5}$ concentration in transportation (car/bus), including results of both ger and apartment residents. There were few people using the transportation at dawn, and the measurement results of the dawn did not appear. However, from the morning to late evening when people did their activity, the result was that the concentration increased in the morning, decreased in the afternoon, and increased again in the evening. In the case of other indoors, there were many participants who did not provide information about the location, and there was not enough sample to show the result.

Table 8. Descriptive statistics of the hourly $PM_{2.5}$ concentration in each microenvironments of ger and apartment

Microenvironment	Housing type	$PM_{2.5}$ concentration ($\mu g/m^3$)					
		GM (GSD)	Min	25th	50th	75th	Max
Home	Ger	46.6 (2.6)	1.8	25.2	48.2	88.3	364.5
	Apartment	22.0 (2.5)	0.5	14.3	22.9	39.0	187.8
Workplace	Ger	36.0 (3.4)	0.2	16.8	35.7	90.5	452.7
	Apartment	25.4 (2.8)	1.0	13.8	24.2	55.3	217.9
Outdoor	Ger	34.3 (2.6)	3.6	23.5	33.5	59.3	261.6
	Apartment	29.0 (2.3)	3.6	16.5	25.1	52.3	201.8
Car/Bus	Ger	23.8 (2.6)	4.9	12.6	21.3	39.7	187.4
	Apartment	17.7 (3.0)	1.7	8.7	19.4	32.8	394.5

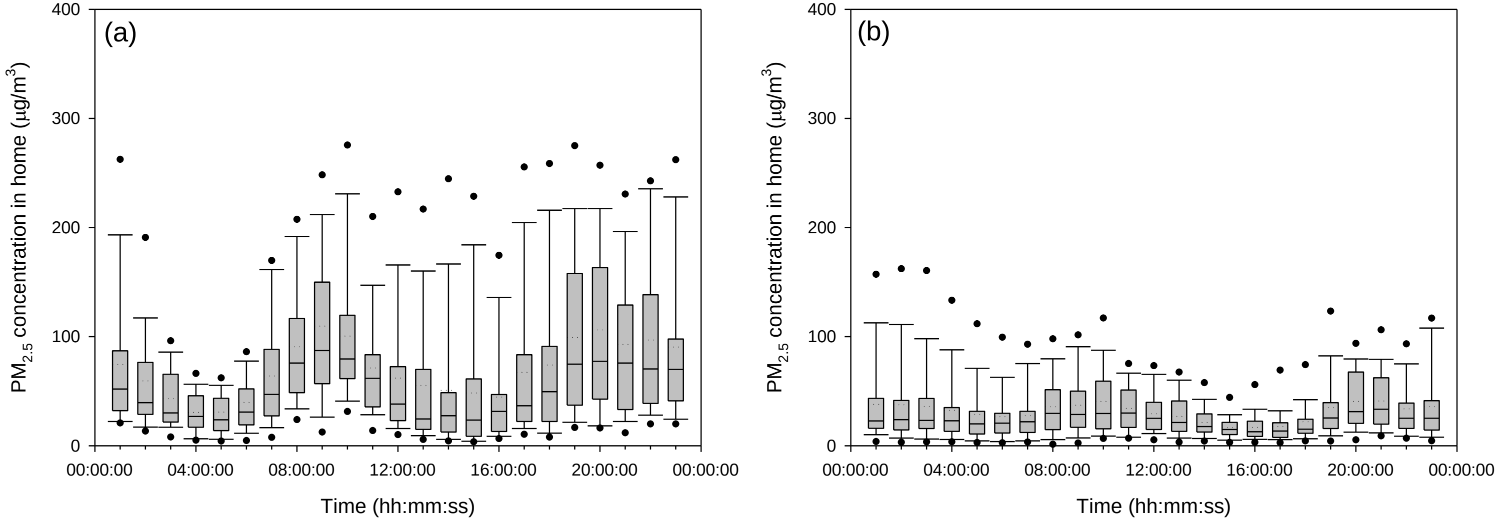

Figure 7. Hourly average $PM_{2.5}$ concentration in home (a) ger residents (b) apartment residents. The dotted line within the box indicated the mean.

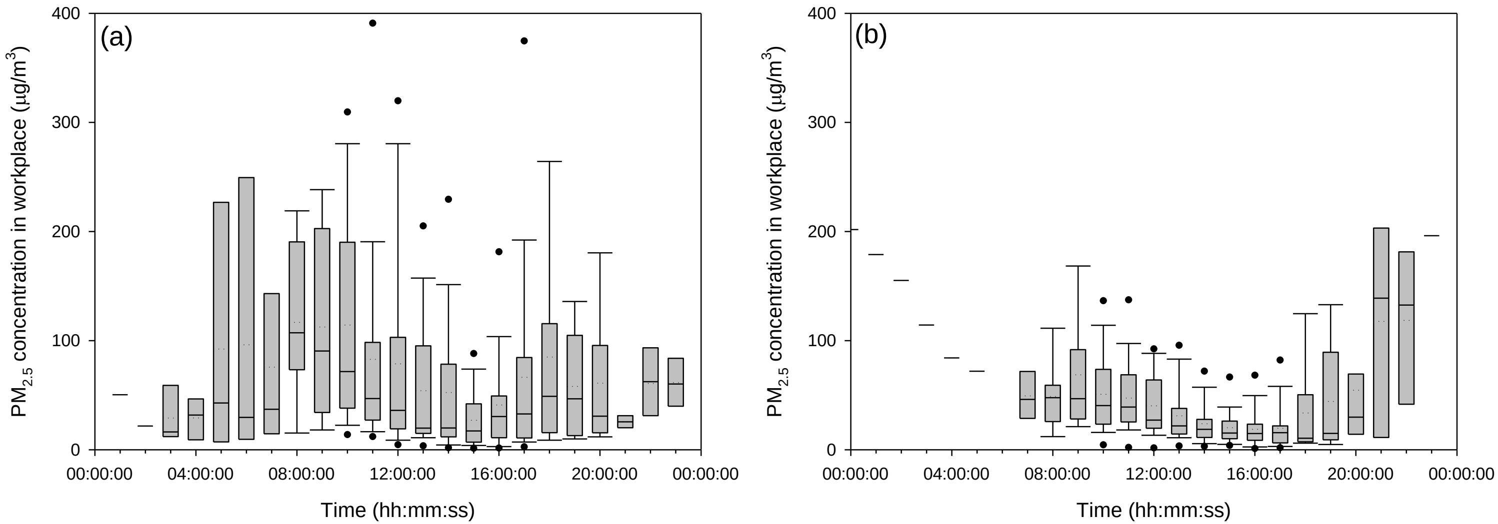

Figure 8. Hourly average $PM_{2.5}$ concentration in workplace (men only) (a) ger residents (b) apartment residents. The dotted line within the box indicated the mean.

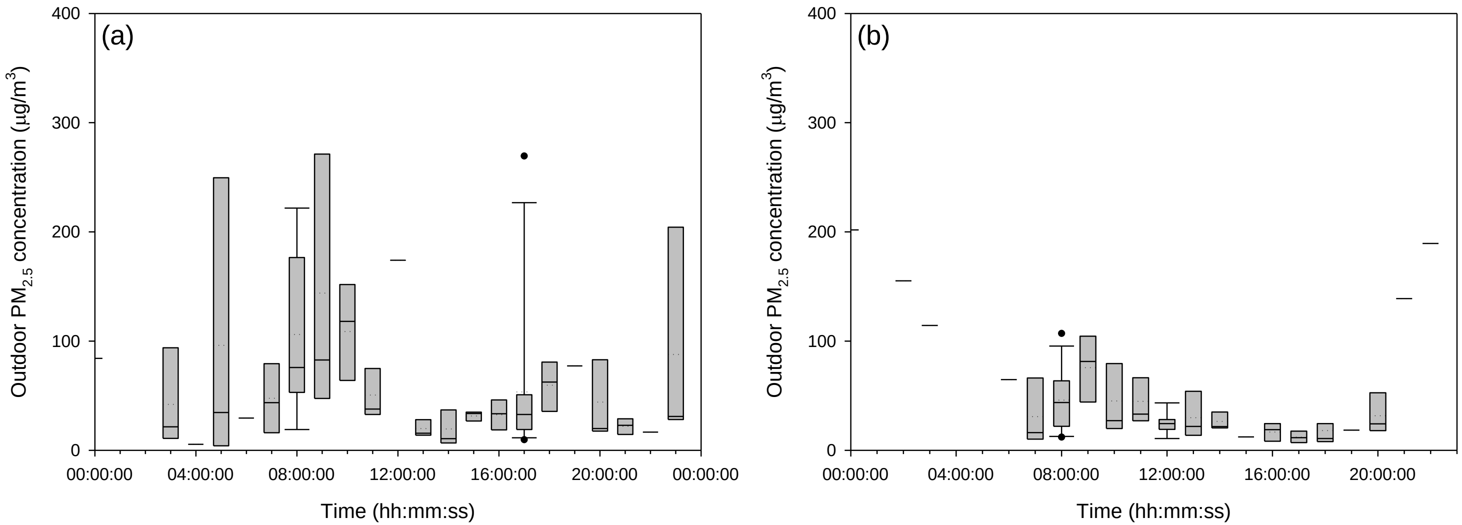

Figure 9. Hourly average outdoor $PM_{2.5}$ concentration (a) ger residents (b) apartment residents. The dotted line within the box indicated the mean.

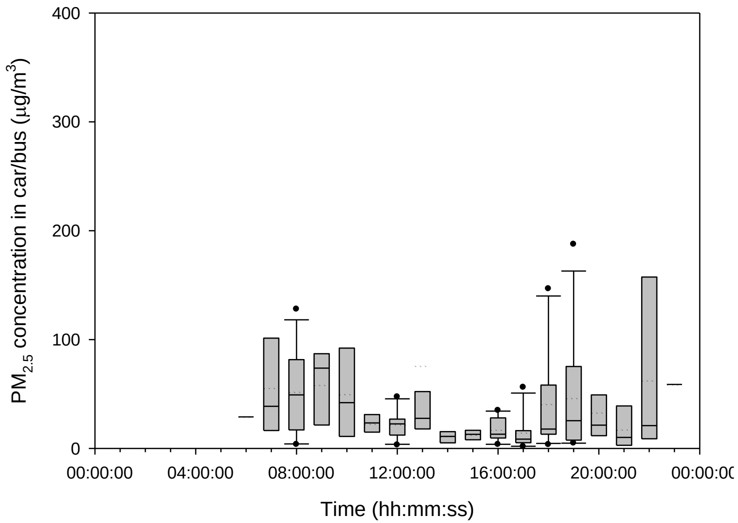

Figure 10. Hourly average $PM_{2.5}$ concentration in car/bus. The dotted line within the box indicated the mean.

3.5 Relationship with ambient $PM_{2.5}$ concentration

Figure 11 showed hourly variation of ambient $PM_{2.5}$ concentration during sampling period provided by the U.S. embassy in Ulaanbaatar. Descriptive statistics of the ambient $PM_{2.5}$ concentration at each week during sampling period was shown in table 8. The location of the U.S. embassy was also shown in figure 13. The variations of each weeks were shown, and the error bar showed the standard deviation. The maximum was at 10 a.m., and the minimum was at 5 p.m., commonly.

Figure 12 indicated the 24-hour variation of the I/O ratio at home during the stay of the wife. Ger residents had a higher average I/O ratio than apartment residents, with a maximum at 3 p.m. and minimum at 4 a.m. Apartment residents had the maximum I/O ratio at 1 p.m. and the minimum at 10 a.m. The I/O ratio increased in the afternoon when the ambient $PM_{2.5}$ concentration was low and decreased in the morning.

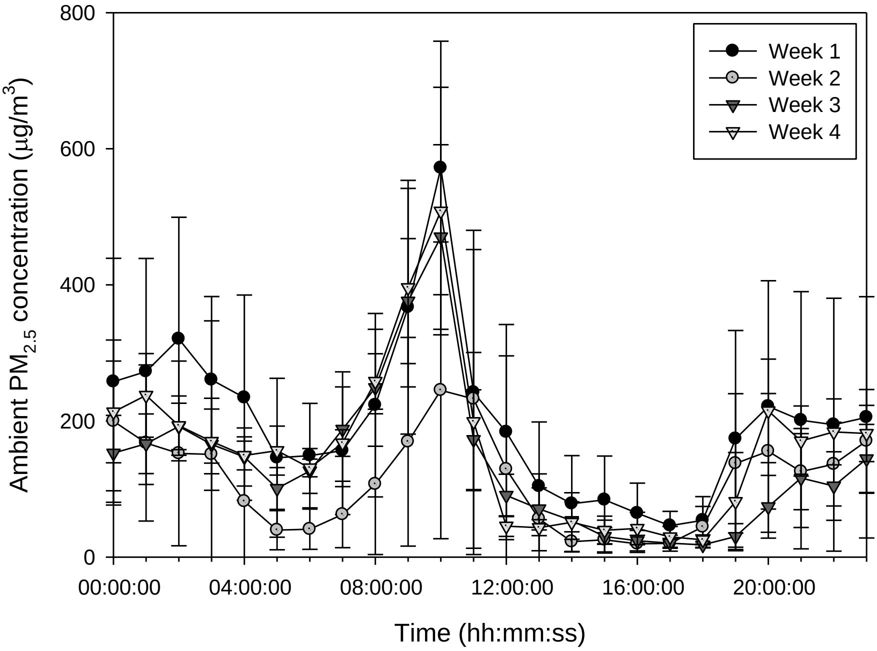

Figure 11. Hourly variation of ambient $PM_{2.5}$ concentration provided by U.S. embassy in Ulaanbaatar during sampling period (The error bar indicated the standard deviation of each item.)

Table 9 Descriptive statistics of ambient $PM_{2.5}$ concentration at each week of sampling

Period	Week	Ambient $PM_{2.5}$ concentration ($\mu g/m^3$)		
		GM (GSD)	Minimum	Maximum
20th to 26th, Jan.	1	169.8 (1.9)	34.2	334
27th, Jan. to 9th, Feb.	2	86.4 (2.3)	27.3	227.9
10th to 16th, Feb.	3	98.9 (2.4)	17.9	158.8
17th to 23rd, Feb.	4	121.7 (2.3)	25.4	184.2

* 3rd to 9th February were excluded from sampling period, including Lunar new year.

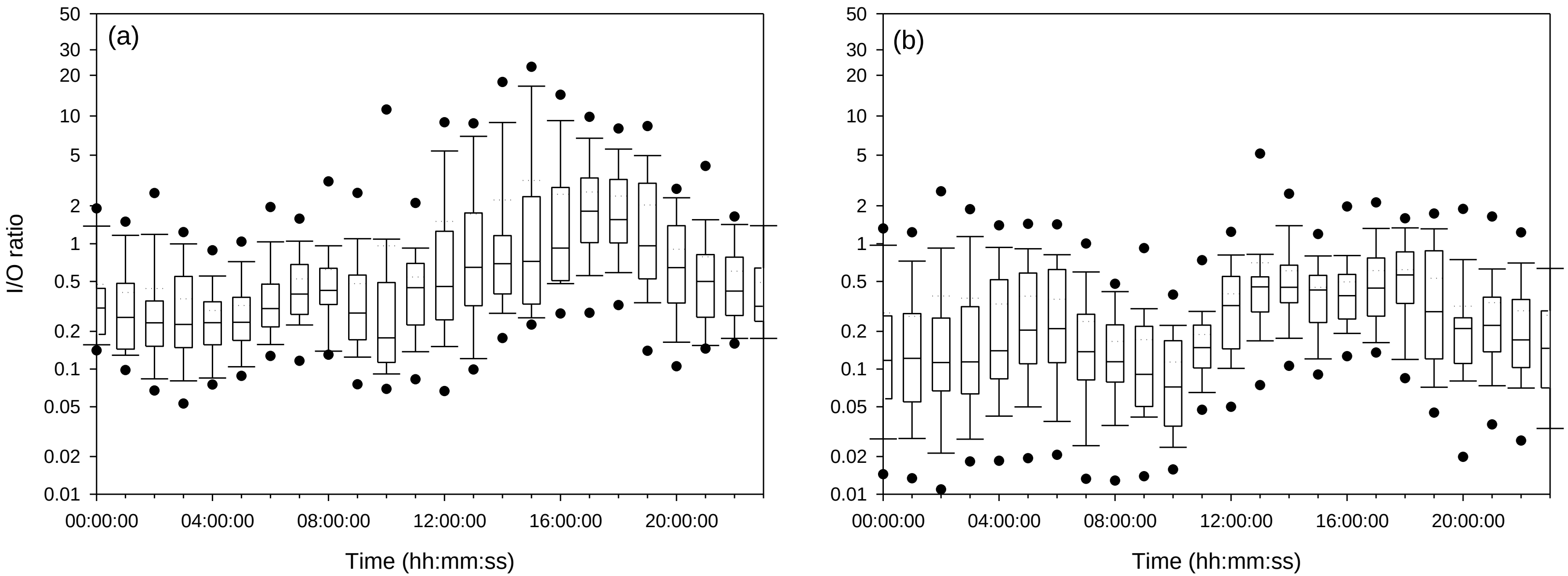

Figure 12. The 24-hour variation of I/O ratio at home during the stay of wife (a) ger and (b) apartment

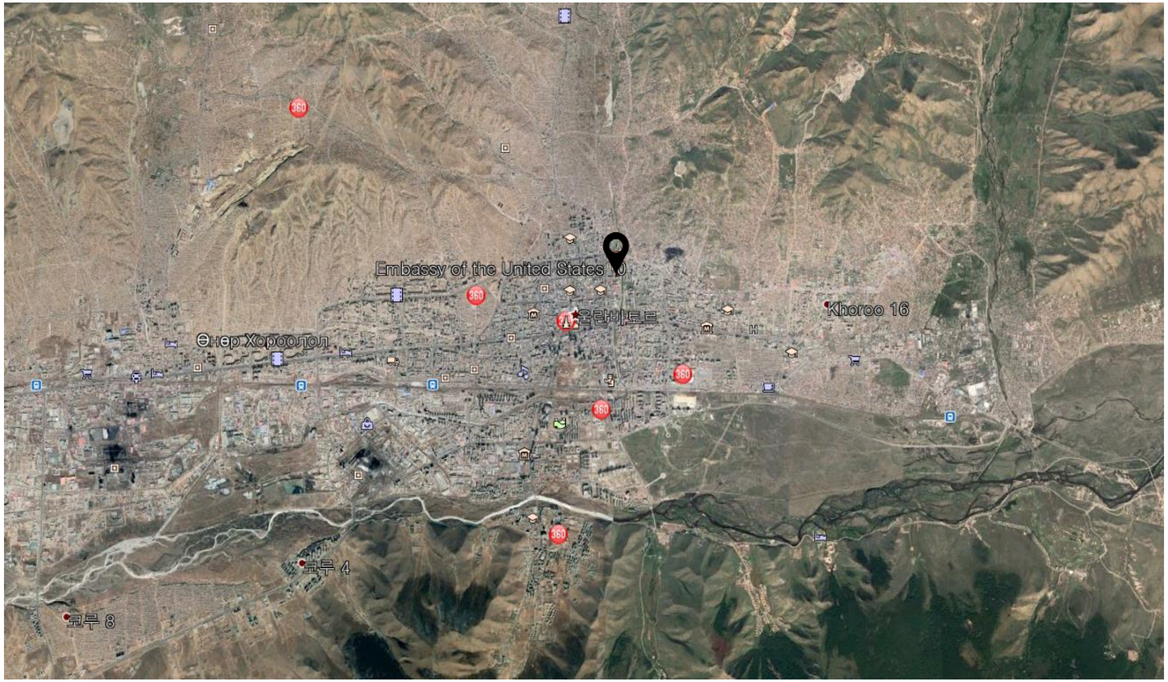

Figure 13. Location of U.S. embassy in Ulaanbaatar that measured and provided the ambient $PM_{2.5}$ concentration

3.6 Time-activity pattern

Table 9 showed time-activity patterns of the couples by housing type. All study participants spent most of their time indoors. Husband of ger spent an average 12.8 ± 4.2 hours at home and 9.2 ± 3.4 hours at workplace. Husband who live in apartment spent an average of 11.2 ± 4.1 hours at home and 7.4 ± 3.5 hours at work. Husband living in ger had a longer working time than the husband living in apartment. The time spent outdoors was longer for the husband living in ger, and the husband living in apartment spent longer than ger residents on the transportation.

Wife spent more than 90% of the day at home. The average spent time of wife who live in ger and apartment were 21.7 ± 3.0 hours and 21.7 ± 3.2 hours at home, respectively. The time spent outdoors were 1.8 ± 1.8 hours and 0.9 ± 0.7 hours at home, respectively. The number of wife who did not go out at all during the day were 7 for wife living in ger and 6 for wife living in apartment. Wife living in ger also spent longer time in transportation than wife living in apartment. Research participants who reported information about other indoors visited restaurants, cafes, and relatives' homes. However, most research participants did not provide information about other indoors.

Table 10. Time-activity patterns of couple by housing type

Couple	Microenvironment	Time spent (hour)	
		Ger	Apartment
Husband	Home	12.8 ± 4.2	11.2 ± 4.1
	Workplace	9.2 ± 3.4	7.4 ± 3.5
	Outdoor	2.0 ± 1.3	1.3 ± 1.4
	Car/Bus	1.5 ± 1.3	2.4 ± 2.2
	Other indoors	1.1 ± 0.6	1.8 ± 1.2
Wife	Home	21.7 ± 3.0	21.7 ± 3.2
	Outdoor	1.8 ± 1.8	0.9 ± 0.7
	Car/Bus	2.1 ± 1.9	1.8 ± 0.9
	Other indoors	1.4 ± 1.1	1.7 ± 1.4

3.7 Microenvironmental contribution

Table 10 showed the contribution of each microenvironment to 24-hour personal exposure to $PM_{2.5}$. The minimum contribution of home to personal exposure of husband living in apartment was 0.4%, the median was 48.6%, and the maximum was 96.7%. The contribution of workplace showed 4.5% at minimum, median 34.2%, and maximum 78.5%. Outdoor contributed at least 0.5%, median 4.6%, and maximum 31.3% and for 0.7%, 8.1%, and 35.3% for transportation. For wife living in apartment, home contributed to personal exposure at least 37.4%, median and maximum at 100%. Outdoor, contribution was 0.1% at minimum, median 3.9%, and maximum 14.4%. Personal exposure to $PM_{2.5}$ of wife living in apartment was contributed by transportation 0.4% at minimum, median 4.5%, and 6.5% at maximum.

In the case of wife, both ger and apartment residents showed the contribution of over 90% at home. Contribution to personal exposure of the husband living in ger was the minimum at 15.8%, the median at 57.8%, and the maximum at 82.4%. The median value of outdoor contribution was 8.4%, the maximum was 23.3%, and 3.3% and 17.8% for transportation, respectively. For the wife living in ger, the minimum contribution at home was 66.3%, median 99.3%, and maximum 100%.

Table 11. Contribution of each microenvironment to 24-hour personal exposure to $PM_{2.5}$

Couple	Microenvironment	Contribution (%)	
		Ger	Apartment
Husband	Home	57.9 ± 22.7	50.3 ± 22.9
	Workplace	36.5 ± 19.8	34.5 ± 19.6
	Outdoor	9.1 ± 5.3	7.0 ± 7.3
	Car/Bus	5.7 ± 5.5	10.0 ± 8.8
	Other indoors	2.6 ± 1.3	8.3 ± 6.2
Wife	Home	94.3 ± 8.8	95.2 ± 12.1
	Outdoor	7.3 ± 6.9	4.5 ± 4.0
	Car/Bus	6.5 ± 4.3	4.0 ± 2.4
	Other indoors	3.4 ± 2.9	12.5 ± 17.0

3.8 Action radius

Table 11 showed the action radius of 4 groups of research participants. Using the acquired GPS data, the areas of route for each participant in two-day were obtained. The average action radius of ger residents was 8.1 ± 14.1 km^2, and that of apartment residents was 6.0 ± 10.1 km^2. The variation of the action radius among participants was very large. The action radius of husband and wife living in ger and apartment were 15.0 ± 17.4 km^2, 1.6 ± 4.0 km^2, 9.8 ± 10.2 km^2, and 2.9 ± 8.9 km^2, respectively. Wife had a long stay at home and had the smaller action radius than husband.

Table 12. Descriptive statistics of the action radius of research participants

Couple	Action radius (km^2)					
	Ger			Apartment		
	Min	50th	Max	Min	50th	Max
Husband	0.2	5.5	67.2	0.2	5.9	33.5
Wife	0.0	0.0	14.6	0.0	0.2	37.2

3.9 Ratios between different particle sizes

Size of PM can be differed by sources of natural and anthropogenic activities (Oanh et al., 2006). Ratios of Coarse to Fine PM (CFR) can be used for determination of PM emission source (Querol et al., 2004). If the ratio of $PM_{2.5}$ to PM_{10} is larger than 0.60, it meant that it was caused by an anthropogenic activities such as combustion (Jaafari et al., 2018). Relatively small CFRs were attributed to natural sources such as mineral dust, re-suspended local top soil, and road surface dust (Chan and Yao, 2008).

Table 12 showed the ratios of $PM_{2.5}$ to PM_{10} (CFR_1). CFR_1 were 0.8 or more and there was no statistically significant difference between ger and apartment. There was a statistically significant difference in CFR_1 between the couples living in apartment, whereas there was no significant difference between the couples of ger. Husband of ger showed significant difference in CFR_1 by each microenvironment. It was highest at home and other indoors, and lowest at workplace. In contrast, CFR_1 of wife living in ger had no difference by microenvironment. For apartment, the wife had the highest CFR_1 at home and the lowest in other indoors.

Ratio of PM_1 to $PM_{2.5}$ (CFR_2) was indicated in table 13. CFR_2 showed a value of 0.6 or more in most cases. The CFR_2 of the apartment was higher than that of ger, and the residents of the apartment were exposed to finer particles. The wife of both housing types had higher values than husband. When divided by microenvironment, CFR_2 of the apartment residents at home and workplace were higher than those of the ger residents.

Table 13. Ratios between $PM_{2.5}$ and PM_{10} by housing type, couple, and microenvironment

Housing type	$PM_{2.5}/PM_{10}$	Couple	$PM_{2.5}/PM_{10}$	Microenvironment	$PM_{2.5}/PM_{10}$
Ger	0.86 ± 0.06	Husband	0.85 ± 0.07	Home	0.87 ± 0.06
				Workplace	0.83 ± 0.08
				Outdoor	0.86 ± 0.07
				Car/Bus	0.85 ± 0.06
				Other indoors	0.87 ± 0.06
		Wife	0.87 ± 0.05	Home	0.87 ± 0.05
				Outdoor	0.85 ± 0.06
				Car/Bus	0.87 ± 0.06
				Other indoors	0.84 ± 0.06
Apartment	0.87 ± 0.06	Husband	0.87 ± 0.07	Home	0.88 ± 0.06
				Workplace	0.86 ± 0.07
				Outdoor	0.86 ± 0.07
				Car/Bus	0.87 ± 0.07
				Other indoors	0.83 ± 0.08
		Wife	0.88 ± 0.06	Home	0.88 ± 0.06
				Outdoor	0.85 ± 0.07
				Car/Bus	0.87 ± 0.06
				Other indoors	0.85 ± 0.06

Table 14. Ratios between PM_1 and $PM_{2.5}$ by housing type, couple, and microenvironment

Housing type	$PM_1/PM_{2.5}$	Couple	$PM_1/PM_{2.5}$	Microenvironment	$PM_1/PM_{2.5}$
Ger	0.62 ± 0.08	Husband	0.60 ± 0.08	Home	0.61 ± 0.07
				Workplace	0.59 ± 0.10
				Outdoor	0.60 ± 0.09
				Car/Bus	0.62 ± 0.07
				Other indoors	0.61 ± 0.06
		Wife	0.63 ± 0.07	Home	0.63 ± 0.07
				Outdoor	0.61 ± 0.07
				Car/Bus	0.64 ± 0.03
				Other indoors	0.63 ± 0.04
Apartment	0.65 ± 0.06	Husband	0.64 ± 0.06	Home	0.66 ± 0.05
				Workplace	0.63 ± 0.06
				Outdoor	0.63 ± 0.05
				Car/Bus	0.63 ± 0.08
				Other indoors	0.62 ± 0.08
		Wife	0.66 ± 0.05	Home	0.66 ± 0.05
				Outdoor	0.60 ± 0.09
				Car/Bus	0.63 ± 0.06
				Other indoors	0.63 ± 0.07

IV. Discussion

It has been documented that people with high income lived in apartments, and people with low income lived in ger in Mongolia (Komatsu et al., 2004; Amarsaikhan et al., 2014; Allen et al., 2013). According to the results of this study, 62.5% of ger residents had monthly income less than $1,000 dollars. On the contrary, 56.3% of apartment residents had monthly income over 4,000 dollars. These differences were evident not only at the income level, but also at the education level. People living in apartments had the higher level of education than ger residents. This showed that inequality by income level was also applied to education. In addition, the results were similar to those of previous studies showing a correlation between income and education level (Muller, 2002; Gregorio and Lee, 2002).

Ger and apartment had different housing characteristics such as house structure. Health behaviors were also differed because of these housing characteristics. Ger had toilet outside the house in the form of a conventional toilet bowl made of wood. There was a serious problem of water supply by lengthening the water from the well. Therefore, it is considered that the number of taking a shower, hand washing, and brushing teeth were less than those of apartment residents. On the contrary, apartments' accessibility to the water was good, so it could be considered that the health-related habits were more frequently than the people living in ger.

Twenty four-hour personal exposure to $PM_{2.5}$ of ger residents was higher than apartment residents. Indoor coal burning contributed to the higher 24-hour personal exposure to $PM_{2.5}$ of ger residents. However, apartment residents ventilated more often than ger residents, and many apartment residents with air purifiers may have contributed to the lower 24-hour personal exposure of apartment residents. Also, it was highly correlated with 24-hour personal exposure to $PM_{2.5}$ among couples, and it is highly likely to have a high correlation of personal exposure with family members.

Personal exposure to $PM_{2.5}$ in this study was higher than in other studies or similar to those in developing countries. Personal exposure to $PM_{2.5}$ in the winter was 36.9 ± 28.7 μg/m^3 in Korea (Hwang and Lee, 2018). Twenty four-hour personal exposure to $PM_{2.5}$ was 8.47 μg/m^3 in Utah, USA (Sloan et al., 2016), and 35.4 ± 19.5 μg/m^3 in Hong Kong (Chen et al., 2018). Personal exposure to $PM_{2.5}$ of women living in rural Honduran in Dominican Republic was 60.2 ± 25.7 μg/m^3 (Pillarisetti et al., 2019), similar to the wife living in ger in this study. In Ho Chi Minh of Vietnam, personal exposure to $PM_{2.5}$ was 64.3 ± 33.18 μg/m^3, higher than the results of this study (Vu and Troung, 2017).

For hourly variation of personal exposure, profiles of hourly personal exposure were grouped into 6 clusters. In most of the clusters, personal exposures to $PM_{2.5}$ of all study participants were rapidly increased in the morning. This was because people began their activities in the morning and burned coal indoors. Also, this showed that the additional heating was done in the evening. In the afternoon, the atmosphere was heated by the sunlight and it was considered that heating was not necessary. It is necessary to take measures to reduce personal exposure in the morning hours.

Biomass burning indoors was a significant contributor to $PM_{2.5}$ concentration in ger. Previous studies reported that concentrations of carbon dioxide, heavy metals, and PAHs, as well as $PM_{2.5}$, increased when biomass was burned indoors (Hampson et al., 1994; Viau et al., 2000; Wornat et al., 2001). Although this study did not investigate these pollutants, further studies are needed as ger residents are more likely to be exposed to indoor air pollutants by indoor coal combustion.

The $PM_{2.5}$ concentration in the workplace by husband living in ger was higher than husband living in apartment. Most of the apartment residents were office workers. In contrast, the occupations of the ger residents included truck drivers, construction workers, and carpenter who were exposed to high concentrations of dust (Kirkeskov et al., 2016; Geyh et al., 2010; Lewne et al., 2007). According to the time-activity patterns, the ger residents stayed longer than the apartment residents at workplace, and the percentage of night workers was higher. As a result, personal exposure to $PM_{2.5}$ in the workplace of the ger residents was higher than apartment residents.

The outdoor $PM_{2.5}$ concentration that exposed to ger residents was higher than apartment residents. In the previous study, the average $PM_{2.5}$

concentration in winter in Ulaanbaatar city was 148 μg/m^3 and 250 μg/m^3 in a traditional housing area (Allen et al., 2013). Due to the characteristics of the basin area, $PM_{2.5}$ emitted from the chimney burned coal in gers could be accumulated in the traditional housing area. Especially, the $PM_{2.5}$ concentration in ger area rose to over 250 μg/m^3 in the morning time, so national efforts are needed to reduce the ambient $PM_{2.5}$ concentration in this area.

Husband who had full-time job had a wider action radius than homemaking wife. Individual's action radius would be varied depending on the type of job. Wife living in ger not only stayed in the ger district, but also moved to the city by means of transportation. Wife living in apartment acted in the city where apartments were mainly located. Ger district laced facilities and ger residents had to move into city to use them. On the other hand, apartments were located in the city, showing that the infrastructure to enjoy nearby facilities was well established.

The ambient $PM_{2.5}$ concentration in Ulaanbaatar in January and February showed similar profiles to the personal exposure to $PM_{2.5}$. Previous study showed a high positive correlation between personal exposure to $PM_{2.5}$ and ambient $PM_{2.5}$ concentration (Guak and Lee, 2018). It was also reported that the ambient concentration of fine particles was closely related to the personal exposure to fine particles of children (Janssen NAH et al., 1999).

Based on these, it can be concluded that ambient $PM_{2.5}$ concentration affected personal exposure to $PM_{2.5}$ of research participants in this study.

Ger and apartment residents spent the longest time at home in 5 different environments. In the study of United States, people spent 70.9% of the day (Sexton et al., 2007). In a study conducted in Seoul, Korea, people spent the longest time at home, even though there were time differences depending on the season (Lee and Lee, 2017). In the Canadian Human Activity Pattern Survey 2 (CHAPS), people spent 67.5% of the time in the summer and 72.4% in the winter (Matz et al., 2014). Since people spent the longest time at home, efforts are needed to reduce the exposure to $PM_{2.5}$ at home.

In this study, $PM_{2.5}/PM_{10}$ (CFR_1) showed values above 0.8 in all microenvironments. According to WHO, 0.5 of $PM_{2.5}/PM_{10}$ was a characteristic of urban areas in developing countries and 0.5-0.8 in urban areas of developed countries (Souza et al., 2013). A study of $PM_{2.5}/PM_{10}$ in the northern region of China showed CFR_1 values of 0.5 to 0.64 (Hu et al., 2014). $PM_{2.5}/PM_{10}$ in classroom of Middle Eastern, was 0.16 in autumn, 0.43 in winter, and 0.31 in spring according to season (Elbayoumi et al., 2013). $PM_{2.5}/PM_{10}$ ratios ranged from 0.6 to 0.8 in EU region (Querol et al., 2004). In urban areas, it was 0.4-0.5, and in the Netherlands, Germany and northern and southern Spain, it was 0.8. In Ulaanbaatar, fine particles were released by anthropogenic sources such as coal-fired power plants and indoor coal combustion, resulting the high $PM_{2.5}/PM_{10}$.

There are limitations in this study. First, we divided the microenvironment into 5 categories to facilitate participation of research participants. Some of the research participants provided the information of other indoors, but most of them did not provide the information. Although the location movement was confirmed by checking the longitude and latitude recorded by the GPS module, it was difficult to confirm the location if the participant stayed indoor for a long time.

A linear regression analysis showed that personal exposure to $PM_{2.5}$ was statistically significantly influenced by the housing type and ambient $PM_{2.5}$ concentration. No statistical significance was found for other factors. It would be driven from the temporal resolution or sample size. Also, this study was conducted during the winter, failing to confirm the effect of the seasons on personal exposure. Therefore, further studies are needed to identify the factors effect on personal exposure to $PM_{2.5}$ in Ulaanbaatar, Mongolia.

V. Conclusion

This study determined personal exposure to $PM_{2.5}$ of ger and apartment residents in Ulaanbaatar, Mongolia during the winter and analyzed the factors influencing personal exposure. There was a statistically significant difference in 24-hour personal exposure to $PM_{2.5}$ between ger and apartment residents. As a result of real-time data analysis, the profiles of personal exposure of research participants increased in the morning time and decreased in the afternoon. The hourly ambient $PM_{2.5}$ concentration showed a similar pattern to exposure profiles of research participants. Based on this study, national measures considered the ambient $PM_{2.5}$ concentration will be needed to reduce personal exposure. Housing type and ambient $PM_{2.5}$ concentration showed significant linearity with personal exposure. Indoor $PM_{2.5}$ was due to indoor sources in ger, while it was caused by filtration of ambient air in apartment. Statistical significance was not confirmed for other factors. Additional research is needed to identify factors that affect personal exposure in Ulaanbaatar, Mongolia.

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국문초록

몽골 울란바타르에서 겨울철 입자상 물질의 개인노출 평가

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몽골의 수도 울란바타르는 겨울철 공기 중 높은 $PM_{2.5}$ 농도를 보이며 심각한 대기오염 문제를 겪고 있다. 몽골의 전통 가옥인 게르 주민들은 석탄을 실내 난방 및 조리 연료로 직접 연소한다. $PM_{2.5}$는 석탄 연소로 인해 발생하는 주요 대기오염물질 중 하나로, $PM_{2.5}$ 개인노출의 특성을 파악을 통해 실내 석탄 연소로 인한 건강영향을 예방하는 것이 필요하다. 이 연구는 주거 특성의 차이에 따른 게르와 아파트 거주자의 $PM_{2.5}$ 개인노출을 비교하고,

시간활동패턴이 $PM_{2.5}$ 개인노출에 미치는 영향을 평가하기 위해 수행되었다. 2019년 1월과 2월, 울란바타르의 게르에 거주하는 부부 16쌍과 아파트에 거주하는 부부 16쌍을 대상으로 2일간 입자상 물질 개인노출을 측정하였다. 32쌍의 부부는 풀타임 근로자인 남편과 가정 주부인 아내로 구성되었으며, 모두 비흡연자였다. 입자상물질의 측정 기기로는 Aslung 모니터(Rododo Science, Taiwan)를 사용하였다. 광산식 측정 기기에 의해 측정된 입자상물질의 농도를 중량법으로 측정한 농도로 보정하기 위해 현지에서 상관성테스트를 진행하였다. 시간활동패턴을 기록하기 위해 연구참여자들을 대상으로 48시간동안 머무는 미세환경에 대한 정보를 로그북에 기록하도록 하였으며, 주거 특성을 파악하기 위해 모든 가구를 대상으로 방문 설문조사가 수행되었다. 게르와 아파트 거주자의 24시간 $PM_{2.5}$ 개인노출의 기하 평균은 각각 59.1(1.7)와 26.8(2.0) μg/m³ 였으며, 통계적으로 유의한 차이가 있었다($p<0.001$). $PM_{2.5}$ 농도는 주거 특성에 관계없이 사람들이 활동을 시작한 아침에 증가했으며, 오후에 감소하여 다시 저녁에 증가했다. 선형회귀분석 결과, 주거 형태와 외기 $PM_{2.5}$ 농도가 개인노출에 통계적으로 유의한 영향을 미쳤다 ($p<0.001$). 각 미세환경이 $PM_{2.5}$ 개인노출에 기여하는 정도는 게르 거주자와 아파트 거주자 모두 집에서 가장 컸다. $PM_{2.5}/PM_{10}$ 의 범위는 0.73–0.96로,

$PM_{2.5}$의 발생이 연소와 같은 인위적인 활동에 의한 것임을 확인하였다. 이 연구는 게르 거주자가 실내 석탄 연소로 아파트 거주자보다 $PM_{2.5}$ 개인노출이 높은 것을 확인하였다. 울란바타르 거주자가 석탄 연소에 의해 방출되는 $PM_{2.5}$에 의한 건강영향을 줄이기 위해 외기농도를 고려한 국가적 대책이 필요하다.

주요어: 개인노출, 입자상 물질, 시간활동패턴, 노출평가, 미세환경, $PM_{2.5}$

학　번: 2017-28248

Appendix 1 (Logbook)

Log book for time-activity patterns

Starting date / time	/
Ending date / time	/
Name / Subject ID	/
Number of equipment	AS__________

Day	**Time**		**Where do you stay? (Check √ up to 2)**					**If in home, check you activity**		
			Home	**Workplace**	**Outdoor**	**Car/Bus**	**Other indoors**	**Adding fuel**	**Cooking**	**Passive smoking**
	00:00	00:30								
	00:30	01:00								
	01:00	01:30								
	01:30	02:00								

Appendix 2 (Questionnaire)

Difference of Personal Exposures to $PM_{2.5}$ among Couples in 2 Different Residential Area in Ulaanbaatar, Mongolia	House ID	
	Subject ID	

Thank you for participating in this study about differences of personal exposure to $PM_{2.5}$ among couples in 2 different residential areas in Ulaanbaatar, Mongolia. The aim of this study is to determine microenvironmental impact on personal $PM_{2.5}$ exposure, and to compare personal $PM_{2.5}$ exposure level of Ger and apartment area by microenvironmental impact. The results of this study will help to determine $PM_{2.5}$ exposure level in Mongolia, and to quantitatively compare and analyze $PM_{2.5}$ differences according to the type of residence, in Ulaanbaatar. Your contribution to this research program is essential for the success of this study. The information that you will provide will be encoded, protected, and used for research purposes only.

If you agree to participate in this research, you will be asked to carry a device called ASLUNG to measure $PM_{2.5}$ exposure level for 48 hours. You will be also asked to answer questions to complete questionnaire form. You will also asked to create a logbook to record your time-activity pattern for 48 hours. ASLUNG will record PM_1, $PM_{2.5}$, PM_{10}, CO_2, temperature, and relative humidity, and this results will be identified how much you exposed to them for 48 hours. By signing below, you acknowledge that you agree to participate in this research. Thank you for your participation and support.

I hereby agree to participate in this research.

Name: ____________________

Signature: ____________________

Appendix 2 (Questionnaire)

Difference of Personal Exposures to $PM_{2.5}$ among Couples in 2 Different Residential Area in Ulaanbaatar, Mongolia

House ID	
Subject ID	

<table>
<tr><td>Date</td><td colspan="4">Month , Day , Year 2019</td></tr>
<tr><td rowspan="2">Male ( )
Female ( )</td><td colspan="2">(Name) ________________________</td><td rowspan="2">Number of resident family members including couple</td><td rowspan="2"></td></tr>
<tr><td colspan="2">(Occupation) _____________________</td></tr>
<tr><td>Residence area</td><td colspan="4">□1) Apartment □2) Ger</td></tr>
<tr><td>Birthday</td><td colspan="4">Month□□,Day□□, Year□□□□</td></tr>
<tr><td>Phone number</td><td colspan="4">_________ - _________ - _________</td></tr>
<tr><td>Email address</td><td colspan="4">@</td></tr>
<tr><td>Information of Equipment</td><td colspan="4">AS_______________, SB_______________</td></tr>
<tr><td rowspan="2">Home telephone numbers</td><td rowspan="2">( ) _____ - _____</td><td>Phone number</td><td colspan="2">_____ - ______ - _____</td></tr>
<tr><td>Email address</td><td colspan="2">@</td></tr>
<tr><td>Home address</td><td colspan="4"></td></tr>
<tr><td>Address of workplace</td><td colspan="4"></td></tr>
</table>

Appendix 2 (Questionnaire)

Questionnaire on demographic characteristics

1. What is your height and weight now?

1-1. Height _______cm

1-2. Weight _______kg

2. Up to which level of education did you complete?

- ○ Degree below high school
- ○ High school diploma
- ○ Undergraduate degree (including college)
- ○ Graduate degree or higher

3. What is your average monthly household income during the past six months? (US Dollar)

- ○ Below 500 dollars
- ○ 500 to 1,000 dollars
- ○ 1,000 to 2,000 dollars
- ○ 2,000 to 4,000 dollars
- ○ 4,000 to 6,000 dollars
- ○ 6,000+ dollars

4. What is your position in your current job?

- ○ Self employed
- ○ Employer
- ○ Daily worker
- ○ Family worker
- ○ Temporary worker (contract less than 1 year)
- ○ Regular worker (contract over than 1 year)
- ○ ETC (__________________)

4-1. When did you start working in the jobs listed above? _______________ years ago

Appendix 2 (Questionnaire)

Questionnaire on lifestyle

5. Have you ever smoked more than 400 cigarettes to date?
   - ○ Yes (Move to 5-1)
   - ○ No (Move to 6)

5-1. Do you smoke now?
- ○ Yes
  (This subject is not applicable for this study STOP questionnaire and find another home)
- ○ No, when did you quit? _________ years and ________ months ago

6. Were you exposed to secondhand smoking (passive smoking) recently?
   - ○ No (Move to 7)
   - ○ Yes (Move to 6-1)

6-1. How often were you exposed to someone else's smoke in your house?

○ None	○ Once or twice a week
○ 3 ~ 4 times a week	○ 5 ~ 6 times a week
○ Everyday	

6-2. How often were you exposed to someone else's smoke in other indoor spaces than your home (like workplace)?

○ None	○ Once or twice a week
○ 3 ~ 4 times a week	○ 5 ~ 6 times a week
○ Everyday	

7. Did you ever drink alcohol?
   - ○ Yes (Move to 7-1)
   - ○ No (Move to 9)

7-1. Do you drink alcohol now?
- ○ Yes

  7-1-1. How many years have you drunk in total? ______________ years (Move to 8)

- ○ No, when did you quit? (Move to 9) __________ years and _________ months ago

8. Please indicate the average number of times you have consumed during the past year and the amount of one serving.

	Beer	Vodka	Airag	Arkhi	others
Once or twice a month	○	○	○	○	○
Once or twice a week	○	○	○	○	○
Almost everyday	○	○	○	○	○

9. What is the average sleeping time per day, including naps during the last 6 months?

- ○ Less than 5 hours
- ○ 6 ~7 hours
- ○ 8 ~ 9 hours
- ○ Over 10 hours

10. How many times do you take a shower in a week?

- ○ Never
- ○ Once or twice a week
- ○ 3 ~ 4 times a week
- ○ 5 ~ 6 times a week

11. How many times do you wash your hands in a day?

- ○ Less than 3 times
- ○ 3 ~ 10 times a day
- ○ Over 10 times
- ○ I don’t know

12. How many time do you brush your teeth in a day?

- ○ Never
- ○ Once a day
- ○ Twice a day
- ○ Over 3 times a day

Appendix 2 (Questionnaire)

Questionnaire on living environment

13. How many years have you lived in your current home?

- O 0 ~ 1 year
- O 2 ~ 5 years
- O 6 ~ 10 years
- O Over 10 years

14. When has your house been built?

- O After 2010
- O 2000 ~ 2009
- O 1990 ~ 1999
- O Before 1989

15. How many rooms are in your current home?

- O 1
- O 2
- O 3
- O 4
- O 5
- O Over 6

16. Please indicate the type of heating and cooking fuel and type of fuel you are currently using in your house.

(Check all apply)

Type of heating	Heating fuel	Cooking fuel
O Central heating	O Gas	O Gas
O Single heating	O Oil	O Oil
O Using stove	O Fuel	O Fuel
O Other (____)	O Wood	O Wood
O None	O Electricity	O Electricity
	O Other (______)	O Other (_____)
	O None	O None

17. Do you or your family member cook in your house?

- O Yes (Move to 17-1)
- O No (Move to 18)

17-1. How many times do you or your family member cook in a day?

- O Once a day
- O Twice a day
- O Three times a day
- O Over 4 times

17-2. Is your kitchen separated from your living room?

- O Yes
- O No

18. Is your toilet in the house or outdoor?

- O Indoor
- O Outdoor

19. Please indicate how you ventilate your home.

- O Window opening
- O Operating fans
- O Other (_______________)
- O None

19-1. How many time do you ventilate your home a day in average?

- O Almost not
- O 1 ~ 2 times a day
- O 3 times a day or more

20. Do you currently raise pets indoors?

- O Yes (Move to 20-1)
- O No (Move to 21)

20-1. What kind of pets you raise now (check all)?

- O Dog
- O Cat
- O Bird
- O Other (________________)

21. How do you or your family member clean your home (check all)?

- O Use vacuum cleaner
- O Use a broom
- O Water cleaning
- O Other (________________)

21-1. How many time you or your family member clean your home?

- O Almost not
- O 1 ~ 2 times a week
- O 3 ~ 4 times a week
- O 5 ~ 6 times a week
- O Everyday

22. Do you own the air purifier?

- O Yes
- O No

Appendix 2 (Questionnaire)

23. Please draw your house profile.

* Please indicate toilet location, kitchen location, door and window location, home appliances and furniture.

Appendix 2 (Questionnaire)

Questionnaire on outdoor environment

24. What is the distance from the nearest road (the road on which the bus goes) to the house where you live?

- ○ Within 50 m
- ○ Within 100 m
- ○ Within 500m
- ○ Over 500 m
- ○ None
- ○ Don't know

24-1. How many lanes are the closest adjacent roads you answered above? (combine both directions)

- ○ 2-lane
- ○ 4-lane
- ○ 6-lane
- ○ 8-lane or more

25. Please indicate all facilities (within 1 km) that are near your current home and write about how far away from your house.

Type of facilities	Presence	Distance from your house
Garbage incinerator	○	____________ m
Garbage landfill	○	____________ m
Sewage treatment plant	○	____________ m
Factory	○	____________ m
Chemical treatment plant	○	____________ m
Crematoria	○	____________ m
None	○	____________ m
Other	_____________	____________ m

Appendix 2 (Questionnaire)

Questionnaire on current health status

26. If you are suffering from diseases listed below, pleases indicate to under table.

Acute disease	Not diagnosed but symptomatic	Diagnosis	Are you taking medicine?	How long do you have?
Respiratory diseases	◯	◯	◯	______ months
Heart diseases	◯	◯	◯	______ months
Eye abnormality	◯	◯	◯	______ months
Skin abnormality	◯	◯	◯	______ months

♥ Thank you for answering the questionnaire. ♥