Daytime profile of residential $PM_{2.5}$ concentrations in a ger, a traditional residence in Mongolia

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Abstract

The residents of a ger, a traditional house type in Mongolia, use coal for cooking and heating. The use of unprocessed coal can adversely affect indoor air quality. In this study, the daytime indoor $PM_{2.5}$ concentration in gers was measured by a real-time PM monitor, while the behavior of the residents in using a stove for heating and cooking was also observed. The indoor $PM_{2.5}$ concentration was 208±173 $\mu g/m^3$ (n=28). Although coal was the main fuel, the residents also used other solid fuels such as wood, plastic, rubber, and garbage. High indoor $PM_{2.5}$ concentrations were observed in the morning, and the daytime temporal profile also suggested a high $PM_{2.5}$ concentration at night-time. The stove and fuel types were not significantly associated with indoor $PM_{2.5}$ levels. Further study is needed to determine the effect of stove type through 24 hours of indoor air quality monitoring.

keywords: *Mongolia, $PM_{2.5}$, indoor air, ger*

Introduction

Nearly 50% of the population in developing countries use solid fuels [1]. Solid fuels are often burned in traditional open stoves without a proper ventilation system. Thus, a significant level of indoor air pollution occurs due to incomplete combustion [2, 3]. Among the various solid fuels, the World Health Organization (WHO) recommends against the use of unprocessed coal in the indoor environment [4, 5].

Indoor air pollution related to the burning of solid fuel for heating and cooking in a house affects human health. Coal combustion in a house has been linked to respiratory illnesses, lung cancer, chronic obstructive pulmonary disease (COPD), immune system impairment, and reduction in lung function in China [6]. The $PM_{2.5}$ related to biomass burning has been associated with hospital admissions for respiratory diseases in children under the age of 5 in Cuiabá city [7]. In Shanghai in China, past use of coal among women was associated with all-causes mortality [8].

About 1.2 million people reside in Ulaanbaatar (UB), the capital city of Mongolia, accounting for more than 40% of the population of Mongolia [9]. The city has a peri-urban ger area where a significant part of the UB population is living in a ger. According to the UB Statistics Department, there are about 164,127 households in the ger areas of six districts surveyed by World Bank (WB) at the end of 2011, an increase of approximately 42,000 since the end of 2007 [10].

A ger is a traditional Mongolian house, which has a one-room tent structure with five or, in some cases, six walls, and typically with an average floor area of 28 m^2. The stove for heating and cooking is located in the center of the ger. Households living in a ger in UB are costly to keep warm and

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comfortable because UB is the coldest capital in the world with an average daily temperature of about -13℃ and an average night temperature of -40 ℃. The stove is used throughout the winter months from October to March. With the heavy use of coal, indoor and outdoor air pollution in UB can be very high during the winter.

The purpose of this study was to measure indoor $PM_{2.5}$ levels in gers, and determine the effects of cooking and heating on indoor $PM_{2.5}$ levels. The indoor $PM_{2.5}$ levels were measured in 28 gers during the daytime, and cooking and heating activities were observed continuously.

Methods

Study setting

This study was conducted in 28 gers within the 17th sub-district of Bayanzürkh District, UB, Mongolia. The 28 households were recruited by sub-district family clinics. Measurements and observations were conducted during the daytime (11:00 ~ 18:00) in January 2016. The indoor $PM_{2.5}$ concentration, temperature, and relative humidity were measured simultaneously in all 28 gers for four days. Two researchers in each ger observed the stove use behavior of the residents, including fuel type, the timing of placing fuel in the stove for heating and cooking, amount of fuel used, the time of cooking, and other behavior related to the $PM_{2.5}$ concentration (opening the stove, smoking, burning herbs, and using a vacuum cleaner).

Indoor air monitoring

The real-time concentration of $PM_{2.5}$ was monitored using MicroPEM (RTI Inc., USA). MicroPEM uses a nephelometer recording data every 10 seconds and provides gravimetric sampling, while simultaneously monitoring the real-time concentration. Before commencing the monitoring, the zero calibration of the MicroPEM was conducted with a High Efficiency Particulate Air (HEPA) filter and pre-calibrated at 0.50 L/min with a TSI flowmeter 4146 (TSI Inc., USA). The samples were collected gravimetrically on 3 mm polytetrafluoroethylene filters (PTFE, 25 μm pore) (Zefon International, USA). The filters were conditioned in a dry container for 48 h before weighing. The filters were measured in micrograms using a microbalance (METTLER TOLEDO, Switzerland) in a temperature- and humidity-controlled room. Temperature and relative humidity were measured using HOBO UX100-003 (Onset Computer Corp., USA). The PM monitoring instrument and the HOBO were placed on a table near the wall located approximately 1.2 m from the ground and about 5 m away from the entrance of the ger. The $PM_{2.5}$ concentration values by MicroPEM were adjusted by a filter equipped in MicroPEM filter cassettes. A value below 5 $\mu g/m^3$ recorded by the MicroPEM was changed to 3 $\mu g/m^3$ because the lower limit of the MicroPEM was 5 $\mu g/m^3$. The 1-min averages of the $PM_{2.5}$ concentration were used for the analysis, taking into account the temperature and relative humidity data intervals from HOBO.

Statistical analysis

The 28 gers were summarized only. Twenty of the 28 gers were included in the statistical analysis. Four gers with smoking and four gers with burning herbs or candles were excluded. The geometric mean of $PM_{2.5}$ in the ger was used for statistical analysis. The relationship between the $PM_{2.5}$ concentration and the stove and fuel types was analyzed using the Kruskal-Wallis test. Because the residents in two of the 20 gers did not add additional fuel during the observation period, the analysis between fuel usage and the $PM_{2.5}$ concentration was based on 18 gers. The correlation between the $PM_{2.5}$ concentration and the patterns of stove use (the number of times the stove was opened and fuel usage) was analyzed using the Spearman correlation. The SPSS23 software was used in the statistical analysis.

Results

During the winter of 2011-2012, traditional stoves have been replaced by low-emission stoves (called "improved stoves") by WB's project, as a part of a major effort to reduce outdoor air pollution in Ulaanbaatar [10]. However, there was no significant difference in fuel usage, times of adding fuel, $PM_{2.5}$ concentration, and indoor temperature.

Eighteen of the 28 gers used a traditional stove, while the others used an improved stove. Up to 16 of the 28 gers used coal, 4 used wood, and 8 used coal with additional materials (wood, plastic bags, nut cover, and paper). The average fuel usage in 26 gers was 8758 ± 4074 g, excluding the two gers where no fuel was added during the observation period. The average number of times fuel was added into the stove was 0.4 ± 0.3 times/h. The average $PM_{2.5}$ concentration, temperature, and relative humidity in the 28 gers were 208±173 μg/m^3 (n=28), 23±4℃ (n=27, one home is missing due to malfunction of the monitor), and 21±7% (n=28), respectively. The descriptive statistics of the $PM_{2.5}$, temperature, and relative humidity are listed in Table 1. The average $PM_{2.5}$ concentration in 61% of the gers exceeded 100 μg/m^3 (17 of 28 gers) and was under 50 μg/m^3 in only 2 of 28 gers. The average temperature was over 21℃ in 70% of the gers (19 of 27 gers) and less than 18℃ in 3 of 27 gers.

Overall, the $PM_{2.5}$ concentration was higher in the morning and decreased gradually until late afternoon. Five temporal profiles of the indoor $PM_{2.5}$ concentration in the 28 gers were determined (Figure 1) using the concentration and temporal pattern of the real-time $PM_{2.5}$ concentration. The average $PM_{2.5}$ concentrations in the five groups were 384±171 μg/m^3 (n=10), 171±71 μg/m^3 (n=6), 123±56 μg/m^3 (n=4), 74±27 μg/m^3 (n=5), and 27±20 μg/m^3 (n=3). In the first group, the indoor $PM_{2.5}$ concentrations were very high, and an extreme peak of about 8,500 μg/m^3 was observed. In the second and third groups, the indoor $PM_{2.5}$ concentrations in the morning were 600 and 400 μg/m^3, respectively, and decreased gradually. In the second group, peaks of about 1,100 μg/m^3 occurred in the afternoon. In the third group, less peaks were observed. In the fourth group, the indoor $PM_{2.5}$ concentrations in the morning were 200 μg/m^3. There was a peak of about 180 μg/m^3 in the afternoon. In the fifth group, the $PM_{2.5}$ concentration remained below 50 μg/m^3 in the afternoon.

The correlation between the $PM_{2.5}$ concentration and the pattern of stove use is shown in Table 2. The number of times the stove was opened was significantly associated with the $PM_{2.5}$ concentration. The $PM_{2.5}$ concentration increased when the amount of fuel usage was higher, but they were not significantly correlated (p=0.078). Fuel usage and the frequency of opening the stove were significantly correlated (R=0.77, p-value<0.01). The peak frequency of $PM_{2.5}$ was not statistically correlated with the number of times the stove was opened and the fuel usage.

The differences in the $PM_{2.5}$ concentration based on stove type are listed in Table 3. The $PM_{2.5}$ concentration did not differ based on stove and fuel type. The number of times the stove was opened was significantly higher with the traditional stove. However, 2 of the 5 gers using an improved stove did not add fuel during the observation period. The $PM_{2.5}$ concentration in these two gers were lower than the other three gers. The differences in the $PM_{2.5}$ concentration based on fuel type are listed in Table 4. The peak frequency of $PM_{2.5}$ was higher with the use of mixed fuel. The stove was opened more often when mixed fuel was used.

Table 1. Descriptive statistics of indoor $PM_{2.5}$, temperature, and relative humidity

	AM ± SD	25th percentile	Median	75th percentile	95th percentile
$PM_{2.5}$ concentration (μg/m^3)	208 ± 173	79	163	277	511
Temperature (℃)	23 ± 4	20	23	25	30
Relative humidity (%)	21 ± 7	15	17	25	37

Table 2. Correlation between the $PM_{2.5}$ concentration and pattern of stove use (opening and fuel usage)

		Opening stove (#/h)	Fuel usage (g)
[a] $PM_{2.5}$ concentration (μg/m^3)	R	0.470 *	0.426
	P-value	0.036	0.078
	N	20	18
Peak frequency of $PM_{2.5}$ (#/h)	R	0.362	0.244
	P-value	0.116	0.330
	N	20	18

[a]. the GM of the $PM_{2.5}$ concentration of each ger was used in the analysis.
*. p-value < 0.05

Table 3. Difference in $PM_{2.5}$ concentration based on stove type (*N*=20).

	Traditional (*n*=15)	Improved (*n*=5)	
	AM ± SD	AM ± SD	[b] p-value
[a] $PM_{2.5}$ concentration (μg/m^3)	81.1 ± 49.6	87.6 ± 39.4	0.11
Peak frequency of $PM_{2.5}$ (#/h)	0.35 ± 0.41	0.44 ± 0.35	0.54
Fuel usage (g)	9610.3 ± 4288.9	7860.0 ± 1551.1	0.59
Frequency of opening stove (#/h)	0.46 ± 0.26	0.19 ± 0.25	0.04*
Temperature (℃)	23.6 ± 4.4	22.0 ± 2.0	0.49

[a]. the GM of the $PM_{2.5}$ concentration of each ger was used in the analysis.
[b]. p-value of Kruskal-Wallis test.
*. p-value <0.05

Table 4. Difference in $PM_{2.5}$ concentration based on fuel type (*N*=18).

	Coal (*n*=12)	Mixed coal (*n*=6)	
	AM ± SD	AM ± SD	[b] p-value
[a] $PM_{2.5}$ concentration (μg/m^3)	74.7 ± 48.0	89.5 ± 29.2	0.79
Peak frequency of $PM_{2.5}$ (#/h)	0.34 ± 0.28	0.79 ± 0.35	0.04*
Fuel usage (g)	8078.3 ± 3625.1	10810.8 ± 3957.6	0.14
Frequency of opening stove (#/h)	0.29 ± 0.17	0.54 ± 0.17	0.04*
Temperature (℃)	24.1 3.6	21.9 4.8	0.41

[a]. the GM of the $PM_{2.5}$ concentration of each ger was used in the analysis.
[b]. p-value of Kruskal-Wallis test.
*. p-value <0.05

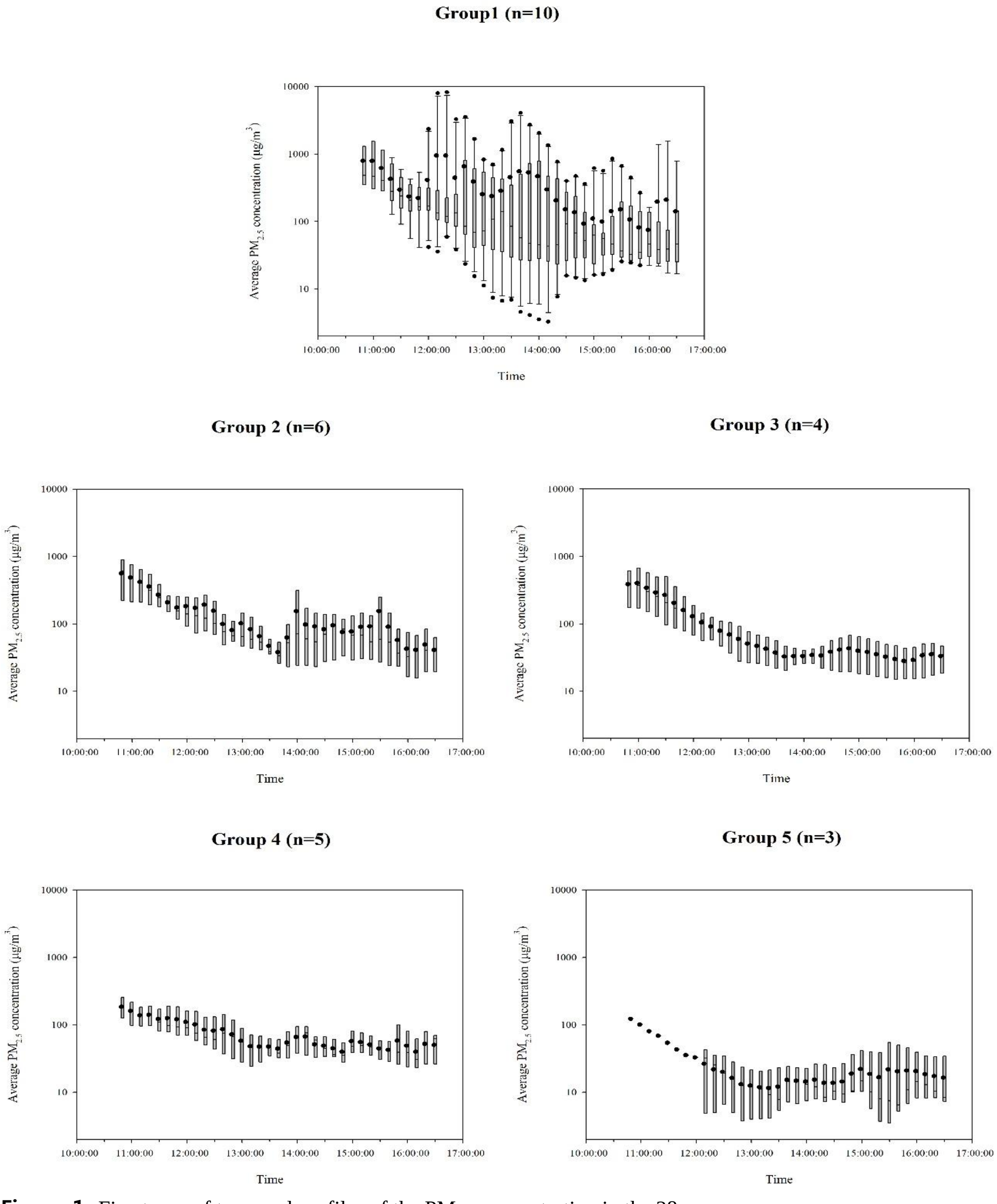

Figure 1. Five types of temporal profiles of the $PM_{2.5}$ concentration in the 28 gers.

The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, respectively. The dots indicate all data points that are outside the 10th and 90th percentiles.

Discussion

The indoor temperature in the gers was on average 23.0 ± 4℃, which was on the high end of the acceptable indoor comfort temperature range. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends an indoor temperature of 19.2 ℃ to 27.8 ℃ in winter [11]. In 4 of the 27 gers, the indoor temperature was greater than 28℃. Such high temperatures suggest the overuse of coal. Education to ensure the reasonable use of coal is required.

The relative humidity was very low (21% on average). Low relative humidity adversely affects human health. Eye and skin irritation may be caused under relative humidity of less than 20% [12-14]. Several reports have recommended maintaining indoor relative humidity above 30% to 40% to prevent drying of the mucous membranes and to maintain adequate ciliary activity [15, 16]. The survival of the rhinovirus and the influenza virus also improved in low relative humidity environments [17, 18]. Particles in dry air can transfer to deeper parts of the respiratory system, because particles can become smaller due to the loss of surface water [19].

Coal combustion for heating and cooking in gers caused high concentrations of PM. The indoor $PM_{2.5}$ concentration was comparable with other studies using solid fuels. In Inner Mongolia, China, the highest respirable particulate matter (RPM) concentration of 719 μg/m^3 was observed in a province with biomass burning in the single cooking/living/bedroom [20]. In the primarily coal-burning provinces, RPM concentrations were 202−352 μg/m^3 in Guizhou and 187−361 μg/m^3 in Shaanxi. In Xuanwei and Fuyuan, China, the geometric means (GM) of indoor $PM_{2.5}$ air concentrations were GM(GSD):162 (2.1) and 136 (2.0) μg/m^3, respectively [21]. In an area of extreme poverty in Metropolitan Santiago, higher pollutant concentrations were observed during hours when heating was used in houses that used coal (mean PM_{10} 250 μg/m^3, CO 42 ppm, and SO2 192 ppb). However, the 24-hour average PM_{10} concentration was 173 ± 14 μg /m^3. In four states in India, the 24-hr concentration of $PM_{2.5}$ in households burning solid cook fuel ranged from 163 μg/m^3 in the living area to 609 μg/m^3 in the kitchen [22].

The temporal profiles of indoor $PM_{2.5}$ concentration tend to include high levels in the morning. It has been suggested that indoor $PM_{2.5}$ concentrations may be higher at night-time. We classified the temporal profiles into five groups. Group 1 with the highest concentration may have been affected by smoking and incense burning. Five of the ten gers in this group had either indoor smoking or incense burning. They used more mixed fuel types and opened the stove more frequently. The proportion of traditional improved stoves did not differ between groups. Groups 2 and 4 had slightly more fluctuating $PM_{2.5}$ concentrations than groups 3 and 5. Only coal was used as fuel in groups 2 and 4. No indoor smoking and incense burning was observed in groups 4 and 5. The stove was opened much less frequently in groups 4 and 5, recorded as 0.2 and 0.3 times/h per house, respectively. Based on the observations, the peaks in the daily profile of the $PM_{2.5}$ concentration coincided with smoking, incense burning, opening the stove for refueling, cooking fried food, and using the vacuum cleaner.

The residents in the ger used various materials for heating and cooking, although coal was the main fuel type. WHO recommends against the use of unprocessed coal in the indoor environment, because it can release various toxic pollutants. However, other materials, such as plastic and rubber, also release toxic chemicals. Plastic combustion can release hazardous chemicals, including, hydrochloric acid, sulfur dioxide, dioxins, furans, and heavy metals, as well as particulates. These emissions are known to cause respiratory diseases, to stress the human immune system, and are potentially carcinogenic. Therefore, the Mongolian government must educate residents to refrain from burning these materials while limiting the burning of unprocessed coal.

The study could not determine the significant factors causing the indoor $PM_{2.5}$ concentration. It was not associated with stove or fuel type. In a previous study, the indoor $PM_{2.5}$ and CO were not significantly decreased by the use of an improved stove [23]. The amount of fuel used was also not associated with the indoor $PM_{2.5}$ concentration. The peak frequency of the $PM_{2.5}$ concentration was higher with mixed coal. In previous research, the indoor PM concentration using coal mixed with additional materials was higher than when using coal only [21]. Further study with a larger sample size should be conducted to determine the significant factors. The temporal profile suggests that the number of times the stove door was opened may be associated with the peak frequency. This may be due to the release of PM during the door opening.

This study was limited by sample size. Because the observation of resident behavior was required, the number of gers studied was limited. However, the observations were important to determine the use of other fuels. The effects of stove type and other factors should be further determined with 24-hour sampling. Another limitation was that ambient air concentrations were not measured. Ambient monitoring was not possible because of extremely cold temperature. In addition, there might be no significant difference in outdoor concentration for four sampling days. Therefore, the effect of the stove usage pattern on indoor $PM_{2.5}$ concentration were valuable information.

Conclusion

The indoor $PM_{2.5}$ concentrations in the gers reached high peak concentrations of up to 8500 $\mu g/m^3$. However, our measurements may have underestimated the 24-hour exposure due to lack of monitoring during the night and early morning. The indoor $PM_{2.5}$ concentration was associated with opening the stove. A stove should be developed where the PM emissions are reduced during the opening of the stove. Further study is also necessary to measure the indoor PM concentration for 24 hours and identify the factors associated with daily indoor exposure in a large sample population.

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