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Research Article

Indoor Air Quality Study among the Households of Ulaanbaatar, Mongolia

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ABSTRACT

This study was conducted to compare whether the indoor air pollutants had changed in 2020 compared to 2019 in accordance with the raw coal use ban. A total 295 households and 10 family health centers were recruited from 6 districts of Sukhbaatar, Bayangol, Chingeltei, Songinokhairkhan, Khan-Uul and Bayanzurkh districts of the Ulaanbaatar city.

The average 24 hours concentration of fine particles is 102.7 $\mu g/m^3$ in total households, which is 2.1 times higher than the Mongolian air quality standard. The average concentration of PM2.5 which was measured in 2019, when the raw coal usage was available, is decreased by 40 percent (from 176.1 $\mu g/m^3$ to 105.7 $\mu g/m^3$) compared to the year of 2020 when improved fuel usage was introduced.

Particulate matter pollution varied significantly by dwelling and heating types. The concentration of indoor PM2.5 was relatively high (128.4 $\mu g/m^3$-150.2 $\mu g/m^3$) in gers and houses with traditional stoves, whereas it was low (81.2 $\mu g/m^3$-86.3 $\mu g/m^3$) in gers and houses with improved stoves.

PM2.5 concentrations varied diurnally in gers, houses and apartments with peak concentrations from 07:00 to 11:00 in the morning (68 $\mu g/m^3$-96 $\mu g/m^3$) and from 18:00 to 20:00 in the evening (71 $\mu g/m^3$-85.5 $\mu g/m^3$).

PM2.5 concentrations varied by district, with relatively low concentrations in Khan-Uul and Sukhbaatar districts (87.9 $\mu g/m^3$) as compared to households in Songinokhairkhan and Bayanzurkh districts (108.1 $\mu g/m^3$).

The average 24 hours concentration of carbon monoxide was 17.6 $\mu g/m^3$ ± 9.2 mg/m^3 in gers and houses, which is 2.5 times higher than the WHO recommended level with higher concentrations in houses than in gers. Compared to the winter of 2019 (176.1 $\mu g/m^3$), the mean concentration of PM2.5 was measured as 105.7 $\mu g/m^3$ (40% lower) in gers/houses who used refined/improved "good" fuel in Jan-Feb of 2020. Thus, indoor PM2.5 concentration in gers and houses had decreased significantly ($p<0.05$) in winter when improved fuels usage was introduced.

Keywords: Raw coal combustion; Improved fuel; Indoor air quality; Households; Coal

INTRODUCTION

Each year at least 7 million deaths occur as a consequence of air pollution, one of the major public health burdens, worldwide (UNECE). Ulaanbaatar has become one of the most polluted cities in the world. According to the research of world bank total suspended particles and carbon monoxide concentrations were higher 27 times and 50 times than WHO recommended guideline in Ulaanbaatar city, respectively. Additionally, researchers found that PM2.5 and PM10 are associated with 23.5% and 19.5% of total respiratory and cardiovascular illness, respectively. The number of vehicles in Ulaanbaatar is increasing every year, and 66% of them have been used at least 10 years already. Exhaust fumes from cars contain nitrogen dioxide, carbon monoxide, particulate matters and volatile organic

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compounds, which constitutes up to 20%-30% of total air pollutants.

The action plan of the national program on environmental health, approvement of the government resolution no. 255 in 2017, was approved by the order no. A/412 of the minister of health in 2017 which aims to implement relevant activities for air pollution mitigation within the framework of objective [1]. In addition, the government of Mongolia issued a decision to ban raw coal consumption by resolution no. 62 of 2018 for citizens, business entities and organizations except for companies licensed to generate electricity and heat in Bayangol, Bayanzurkh, Songinokhairkhan, Sukhbaatar, Khan-Uul and Chingeltei districts from May 15, 2019.

The chemical composition of PM2.5 particles depends on the local and urban climatic factors, human activities, seasonal and diurnal variations. Studies conducted in some US states have shown that outdoor PM2.5 particles are mainly composed of sulfates, ammonium, hydrogen ions, elemental carbon, secondary organic compounds, primary organic compounds from cooking and heating, and some heavy metals from combustion processes. On the other hand, PM10 particles had contained elements related to the earth's crust such as calcium, aluminum, silicon, magnesium, and iron, as well as dust, bacterial spores, and primary organic elements from plant and animal sources [2-5].

Indoor air pollution is one of the leading public health issues in developing countries, as people spend 80 percent-90 percent of their lives in indoor environment, and researchers have found that some indoor pollutants have higher concentrations indoors rather than outdoor environment. The main indoor air pollutants are PM2.5 particles, benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, polycyclic hydrocarbons, radon, trichloroethylene, and tetrachloroethylene, some of which are harmful to human health and can cause cancer.

In developing countries, there are sufficient studies had been conducted on association between indoor air pollution emitted from the solid fuel consumption and acute lower respiratory infections, and pneumonia in children under two years of age. Every two out of five developing countries are using wood, coal, agricultural waste and dung as fuel in the indoor environment. Each year, more than 4 million people die prematurely due to open hearths and the use of solid fuels in their homes. Indoor air pollution is a major cause of non-communicable diseases such as stroke, ischemic heart disease, and chronic obstructive pulmonary disease. As a consequence of intensive indoor air quality research since the 1970's, indoor air pollution sources, pollutant concentrations, health effects, solutions, and various policy measures have been introduced. Secondhand smoking, nitrogen dioxide, formaldehyde, radon and other pollutants emitted from gas-fired stoves have been identified as major risks in newly constructed or under construction buildings recently.

In Mongolia, the use of raw fuels can be associated with PM2.5 particles, sulfur dioxide and carbon monoxide exposures in gers and houses, whereas nitrogen dioxide, formaldehyde, radon emitted from gas-fired stoves and tobacco smoke exposures are frequent in apartments which are harmful for health [6-8].

Currently, there is few indoor air quality studies has been conducted in Ulaanbaatar. According to the study conducted by Enkhjargal, A. et al., PM2.5 concentrations were higher in houses (91.98 $\mu g/m^3$) than in gers (55.16 $\mu g/m^3$) and apartments (42.94 $\mu g/m^3$). Tsevegjav B, et al., had studied the energy efficiency, renewable energy, and improved fuels in gers and revealed the residents' need for sustainable financial support. According to the result of study conducted by Barn, et al., the use of High-Efficiency Particulate Air purifier/filter (HEPA) had reduced PM2.5 particle concentrations by 26 percent in apartments. Furthermore, P. Barn, et al., study has shown that the blood cadmium levels of pregnant women who used HEPA air purifiers were 14 percent lower than in pregnant women who did not use air purifiers in their apartments.

Generally, air pollution research focus on outdoor air quality, while some pollutants concentrations have not yet been fully characterized in indoor environments including public buildings.

Previously in 2019, we measured PM2.5, benzene, carbon monoxide concentrations and microclimate indicators in 180 gers, houses and apartments of Chingeltei and Bayangol districts. It is necessary to identify whether these pollutants concentrations have been changed in the households due to the ban on raw coal consumption since 15 May 2019. Therefore, in this study we aimed to compare if the indoor air pollutants had changed from the previous year in 2019. The goal of the study was to compare indoor air quality of gers/traditional lodging, houses and apartments by districts, by types of fuel and heating, and to develop recommendations for further improvement of indoor air quality.

MATERIALS AND METHODS

This study was conducted using a cross-sectional study design. A total 295 households and 10 family health centers were recruited from 21 sections of Sukhbaatar, Bayangol, Chingeltei, Songinokhairkhan, Khan-Uul and Bayanzurkh districts of the Ulaanbaatar city, respectively (Figure 1).

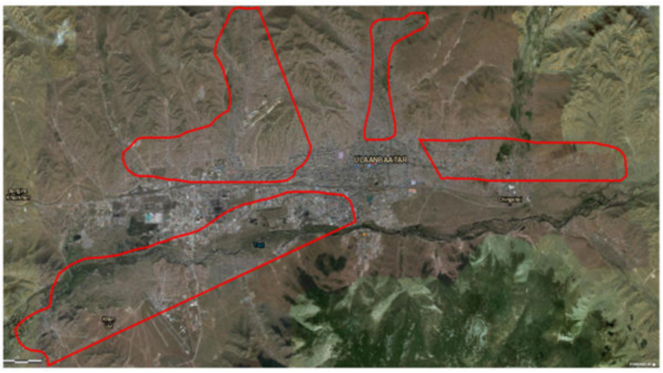

Figure 1: Geographical location of the study households (indicated as red polygons).

We primarily focused on heavily polluted residential areas including 11th, 12th, 14th, 15th, 16th sections of Sukhbaatar district, 5th, 9th, 20th, 23rd, 28th sections of Bayanzurkh district, 5th, 9th, 21st, 25th sections of Songinokhairkhan district, and 6th, 7th, 10th, 11th, 12th, 14th, 16th sections of Khan-Uul district which had covered total of 295 households. These 295 households were consisted of 101 gers, 34 apartments and 160 houses from ger districts. A total of 63 households of Chingeltei and Bayangol districts were re-enrolled from the study conducted in 2019 to compare the indoor air quality between pre- and post "raw coal consumption banning" measure, while 232 households were newly enrolled in this study [9-12].

The main indoor air pollutants and microclimate indicators of the households were measured and the questionnaire was obtained from household participants.

PM2.5 concentrations were measured as for 8 hours and 24 hours using gravimetric and real-time equipment in gers, houses and apartments, whereas microclimatic indicators including air temperature and relative humidity were measured for 24 hours using real-time portable instrument. In addition, the concentrations of carbon monoxide at specific times were measured using real-time equipment. Additionally, carbon monoxide and sulfur dioxide concentrations were measured using passive sampling method with indicator tubes. Air quality measurement was conducted in accordance with the standard operating procedures.

In the questionnaire, 5 categories of 49 questions were asked by the trained data collectors to obtain socio-demographic information of the households and some influencing factors for the pollutants (Table 1).

Table 1: Indoor air sampling methods and equipment.

Variables	Sampling methods	Equipment	Sampling rate and duration
PM2.5 particles	Sampling method and analysis of airborne PM2.5 particles. MNS 6657:2017	Diameter of 37 mm, 2 µm-5 µm pores, PTFE filters, pump, flow calibrator. Dylos DC1700 real-time instrument.	2.0 l/min 4.0 l/min 8 hours and 24 hours 24 hours
Carbon monoxide **(CO)**	ISO 9001 quality requirement	Drager passive detector tubes **CO** monitoring	24 hours real-time
Sulfur dioxide (SO_2)	ISO 9001 quality requirement	Drager passive detector tubes	24 hours

Data collection procedures

Sampling and measurement for PM2.5 particles: A gravimetric analysis, in terms of sampling procedure, cassettes with filters and pumps were placed for 8 hours and 24 hours in the breathing zone, at a distance of 1 meters-1.5 meters away from any sources of pollution according to the "sampling method and analysis of airborne PM2.5 at workplace. MNS 6657:2017" methodology.

- Pump flow rate was measured and calibrated as indicated by the impactor and cyclone manufacturer's guide (either 2.0 l/min or 4.0 l/min) both before and after the sampling to extract airborne PM2.5 particles.
- Total of 10 blank samples have been sent in sampling procedures and analysis along with samples collected from the households for quality control in the laboratory analysis.
- Analyses were conducted in the dust weighing laboratory of occupational and environmental hygiene laboratory, school of public health, Mongolian National University of Medical Sciences (MNUMS), which accredited by MNS/ISO 17025:2018 "general requirements for the competence of testing and calibration laboratories".

Real-time measurements: Dylos DC1700 portable, real-time instrument was used to determine PM2.5 concentrations with 5 minutes of intervals for 24 hours (Figure 2). Measurement information including equipment number, start and end date of measurement were recorded in a log sheet. The Dylos DC1700 was installed in the households, after considering the following factors that may affect the measurement procedure.

These include:

- Away from direct sunlight.
- At least 50 cm away from sources of air movement, such as windows and ventilation ducts.
- Available to recharge and plug in.
- At the breathing zone, 1 m-1.5 m above the ground.
- Keep out of reach of children.
- Away from stoves, at the northern site of gers.
- Living/guest rooms of houses and apartments.

Figure 2: Dylos DC1700 real-time instrument.

Instruments were placed at the most appropriate diurnal time in the households when the participants were available at home. After the measurement, Dylos was connected to a computer using Dylos logger V3.0 software in order to copy the data into the excel, which then converted to dust particles per unit concentration ($\mu g/m^3$) of the international system of units. Since the Dylos DC1700 calculates the PM2.5 particle concentrations in volume of 30 cm^3, the results were obtained using the following equation and compared with the gravimetric method.

Data analysis

We used simple linear regression analysis to assess the relationship between gravimetric method and Dylos DC1700. Statistical analyses were performed using STATA12 software. Absolute values, percentages, mean, standard deviation, minimum values and maximum values were included in the descriptive analysis. The PM2.5 means were compared between groups using the student "t" test, ANOVA, Kruskal-Wallis test and Mann Whitney U test. Indoor air pollutants and microclimate indicators were compared by dwelling types and districts using ANOVA and Kruskal-Wallis tests. We used regression analysis to convert Dylos particle count data into concentrations in the air. The significance level of the p value was considered to be statistically significant if it was less than 0.05 [13-16].

Characterization of gas pollutants in indoor environment

Carbon monoxide concentrations (CO): For the characterization of indoor carbon monoxide concentration, Draeger passive detector tubes (conformed to ISO9001 quality requirements) were placed for 24 hours in households. A total of 100 households including gers (n=46) and houses (n=54) had been enrolled to measure indoor carbon monoxide using passive detector tubes.

Sulfur dioxide concentrations (SO_2): We selected 100 households including gers (n=53) and houses (n=47) to characterize indoor sulfur dioxide concentration using Draeger passive detector tubes (conformed to ISO9001 quality requirements) for 24 hours.

RESULTS

General information of the study households

We recruited a total of 295 households and 10 family health centers including 101 gers (32.8%), 160 houses (53.3%) and 34 apartments (11.9%) from 6 districts of the Ulaanbaatar city. About 56.9% of the study households have 4-6 family members, 37.2% have 1 members-3 members, and a small number of households (5.9%) have more than 6 members. The monthly household income is ranged between 500,000 MNT and 1,000,000 MNT on average (Table 2).

Table 2: General information of the households.

Dwelling types	Number (N)	Percentage (social impact)
Ger	101	32.8
Apartment	34	11.9
House	160	53.3
FHC	10	2
Total	305	100
Family members		
1-3	108	37.2
4-6	165	56.9
More than 6	17	5.9
Total	290	100
Dwelling volume, m^3		

Up to 45	136	55.2
45-80	45	18.2
Above 80	61	25
Total	246	100
Construction year		
Before 2000	49	17.7
2000-2010	114	41.2
After 2010	113	41.1
Total	276	100
Vicinity of major roads, m		
100-200	130	45.4
200-500	46	16.3
More than 500	106	37.5
Total	282	100

Characterization of indoor PM2.5 concentration

Results of indoor PM2.5 concentration using gravimetric method for 24 hours: We used gravimetric method to characterize indoor PM2.5 concentration for a total of 136 households from Sukhbaatar (n=45), Bayanzurkh (n=31), Songinokhairkhan (n=32), Khan-Uul (n=28) districts and 10 FHCs. In terms of dwelling type, 58 (32.8%) gers, 78 (53.3%) houses and 19 (11.9%) apartments were recruited in this analysis (Table 3).

Table 3: Comparison of indoor PM2.5 concentrations by dwelling and heating types (µg/m^3).

Dwelling types	Heating/stove type	N	%	Mean	Standard deviation	Min	Max	P value
Ger	Traditional stove	26	14.1	150.2	116.6	22.3	555.3	0.0051
	Improved stove	32	17.3	81.2	62.5	15.2	255.8	
House	Traditional stove	29	15.7	128.4	96.1	16.7	462.8	
	Improved stove	34	18.4	86.3	56.8	14.4	291.3	
	Electric heater, heat only boilers	28	15.2	81.2	57.2	17.6	288.3	
Apartment	Central heating system	33	19	61.4	50	37.5	290.1	
Total		182	100	102.7	78.2	14.4	555.3	

Both filter-based weighing and Dylos real-time measurements were used to characterize indoor PM2.5 concentration in gers, houses and apartments (Figure 3).

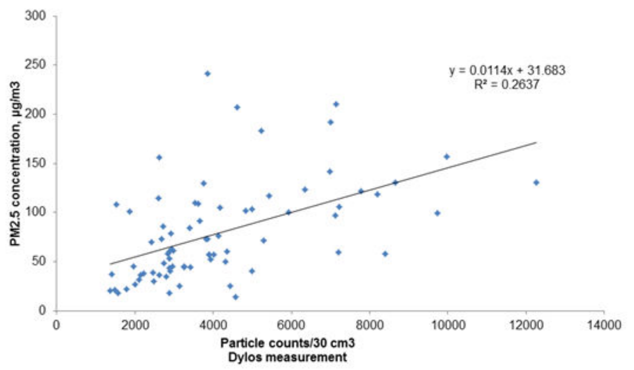

Figure 3: Correlation between DC1700 real-time instrument and gravimetric method.

Using the equation shown above, the number of airborne particles per 30 cm^3 which measured by the Dylos instrument was converted to the standard unit of $\mu g/m^3$ for further statistical analyses.

The mean 24-hour PM2.5 concentration was 102.7 $\mu g/m^3$ (min 14.4 $\mu g/m^3$, max 555.3 $\mu g/m^3$) in total households from 4 districts (Sukhbaatar, Bayanzurkh, Songinokhairkhan and Khan-Uul). In terms of heating type, highest PM2.5 concentrations (138.7 $\mu g/m^3$) were observed in gers/houses with traditional stoves which is 54.9 $\mu g/m^3$ higher (1.7 times) than in households with improved stoves and 60.3 $\mu g/m^3$ higher (1.8 times) than in households with electric heaters and heat only boilers.

The lowest PM2.5 concentration was measured as 61.4 µg/m3 for apartments which connected to the central heating system. However, gers/houses with improved stoves and households with heat only boiler/electric heaters had been measured as relatively moderate (81.2$\mu g/m^3$-86.3 $\mu g/m^3$) PM2.5 concentrations, whereas gers/houses with traditional stoves had been measured the highest (128.4 $\mu g/m^3$-150.2 $\mu g/m^3$) PM2.5 concentration [17,18].

Assuming the fuel type, PM2.5 concentration was measured higher (p=0.904) in households who use raw coal (121.0 $\mu g/m^3$) while it was measured relatively low in households who use improved fuels (105.7 $\mu g/m^3$) (Figure 4).

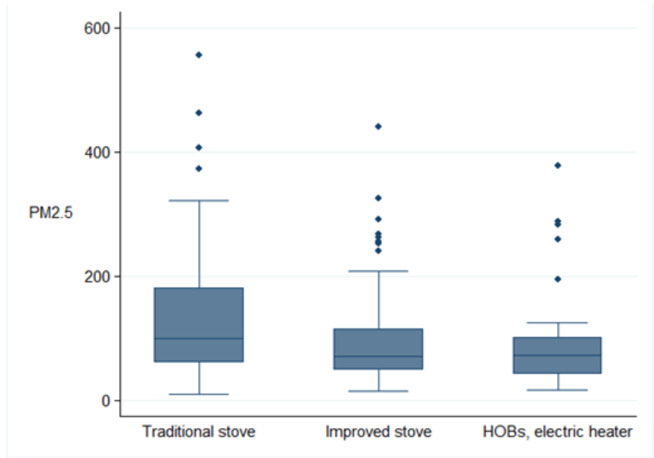

Figure 4: Comparison of indoor PM2.5 concentrations by stove types.

PM2.5 concentration was measured higher in households with traditional stoves while it was measured less in households with heat only boilers/electric heaters regardless of the dwelling type which had a statistically significant difference (p=0.0005). However, there were no significant differences between the district area of the households (p=0.185), dwelling volume (p=0.655) and the distance from the main road (p=0.188) (Table 4).

Table 4: Comparison of indoor PM2.5 concentrations by its influencing factors ($\mu g/m^3$).

Influencing factors	N	%	Mean	Standard deviation	Min	Max	P-value
District							
Bayanzurkh	34	22.5	120.7	117.5	22.3	555.3	0.185
Sukhbaatar	51	33.7	95.4	63.3	15.2	321.2	
Songinokhairkhan	35	23.3	105.5	54	25.6	241.1	
Khan-Uul	31	20.5	92	93.8	14.4	462.8	
Total	151	100	102.7	86.1	14.4	555.3	
Dwelling volume, m^3							
Up to 45	67	45.8	109.3	90.8	15.2	555.3	0.655

45-80	30	20.5	109.3	91	30	462.8	
Above 80	49	33.7	92.1	66.3	16.7	291.3	
Total	146	100	103.5	83.2	15.2	555.3	
Heating type							
Traditional stove	55	36.4	138.7	105.8	16.7	555.3	0.0005
Improved stove	66	43.7	83.8	59.2	14.4	291.3	
Heat only boiler	30	19.9	78.4	56.2	17.6	288.3	
Electric heater							
Total	151	100	102.7	83.1	14.4	555.3	
Fuel type							
Raw coal	50	26.8	121	125.9	16.5	744.8	0.904
Improved fuel	136	73.2	105.7	84.4	14.4	555.3	
Total	186	100	107.3	95.6	14.4	744.8	
Vicinity of major road, m							
Up to 100	25	17.2	120.6	77.5	26.9	318.7	0.188
100-500	85	26.2	104.6	84.4	17.9	555.3	
Above 500	58	40.1	94	80.2	14.4	462.8	
Total	145	100	100.3	81	14.4	555.3	

Indoor PM2.5 concentrations in gers and houses were measured less in Khan-Uul and Sukhbaatar districts (87.9 μg/m^3-95.4 μg/m^3) whereas it was measured relatively higher in Songinokhairkhan and Bayanzurkh districts (108.1 μg/m^3-137.5 μg/m^3).

Results of indoor PM2.5 concentration using gravimetric method for 8 hours: In the gravimetric analysis, 8 hours mean PM2.5 concentration was 105.7 μg/m^3 ± 79.9 μg/m^3 (min 41.8 μg/m^3, max 440.1 μg/m^3) in the study households which have been using improved fuels since Jan-Feb, 2020. In the previous study (conducted in winter, 2019), the 6 hours mean concentration of indoor PM2.5 was 176.1 μg/m^3 ± 120.2 μg/m^3 (min 14.6 μg/m^3, max 562.0 μg/m^3). Compared to the winter of 2019 (176.1 μg/m^3), the mean concentration of PM2.5 was measured as 105.7 μg/m^3 (40% lower) in gers/houses who used refined/improved "good" fuel in Jan-Feb of 2020. Thus, indoor PM2.5 concentration in gers and houses had decreased significantly ($p<0.05$) in winter when improved fuels usage was introduced (Table 5).

Table 5: Comparison of indoor PM2.5 concentrations by the measurement periods (μg/m^3).

Year of measurement	Dwelling type	N	Mean	Standard deviation	Min	Max	P-value
Jan-Feb, 2019	Gers	18	189	130.6	54.1	562	0.013
	Houses	44	226.6	124.5	60.6	615.6	
	(Gers and houses)	62	215.7	126.4	54.1	615.6	

	Total	133	168.2	116.1	11.1	615.6
Jan-Feb, 2020	Gers	7	209.8	151.5	65	440
	Houses	22	102.7	53	41.8	283.1
	(Gers and houses)	29	105.7	79.9	41.8	440.1

Results of indoor PM2.5 concentrations using real-time instruments for 24 hours: A total of 132 households including gers, houses and apartments were enrolled in our Dylos DC1700 real-time measurement and 36 samples of it removed for further analysis due to the instrument chargers damage or extreme values. According to our equation of a regression line, there was moderate correlation (r=0.51) between the parallel measurements of the weighing method and real-time measurements for 76 samples.

The PM2.5 concentration peak (68 μg/m^3-96 μg/m^3) occurred between approximately 0900 and 1100 in the morning while the other peak (71 μg/m^3-85.5 μg/m^3) occurred between 1900 and 2000 in the evening in gers.

In the real-time measurement, the mean indoor PM2.5 concentration is elevated between 0800 and 1200 in the morning (72.04 μg/m^3), and at 1900 in the evening (70.09 μg/m^3) for households. The mean indoor PM2.5 concentration was relatively higher in houses while it was the lowest in apartments. The diurnal variance is significantly high in gers due to the fuel combustion (Figure 5 and Table 6).

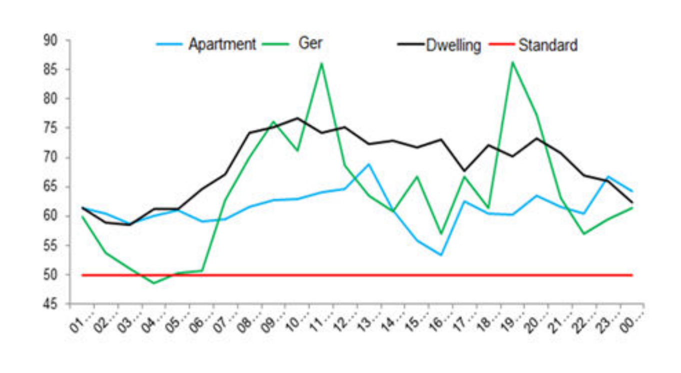

Figure 5: Comparison of diurnal variations in PM2.5 concentrations by dwelling type.

Table 6: Diurnal variations in PM2.5 concentrations using real-time measurement (Dylos), μg/m^3.

Hour	Overall mean	Apartments	Gers	Houses
01:00	61.24	61.46	59.88	61.45
02:00	59.09	60.37	53.8	58.88
03:00	58.47	58.74	51.04	58.45
04:00	60.02	60.12	48.62	61.24
05:00	61.74	61.06	50.2	61.19
06:00	63.46	59.09	50.76	64.72
07:00	65.83	59.57	62.71	67.05
08:00	70.57	61.59	70.02	74.15
09:00	72.45	62.66	76.22	75.2
10:00	71.16	62.88	71.16	76.72
11:00	74.23	64.11	86.09	74.16
12:00	71.81	64.61	68.7	75.18
13:00	69.83	68.84	63.58	72.35
14:00	68.47	60.96	60.78	72.95

15:00	68.44	55.91	66.69	71.83
16:00	66.58	53.44	57.08	73.05
17:00	67.67	62.52	66.84	67.76
18:00	68.34	60.36	61.39	72.13
19:00	70.09	60.32	86.33	70.3
20:00	69.76	63.45	77.34	73.2
21:00	66.91	61.59	63.03	70.85
22:00	61.96	60.48	56.94	66.99
23:00	64.48	66.75	59.49	66.01
00:00	62.21	64.24	61.36	62.44
Total	66.45	61.46	63.75	68.68

According to the checklists in the questionnaire, 37.2% of 196 households had burned fuels 1-2 times over the 24 hours of measurement, and a fuel burning single time was approximately 120 minutes-360 minutes. The households usually burned fuels from 0600 to 0800 in the morning, from 1700 to 1800 and from 2100 to 2200 in the evening, respectively. Activities such as smoking (n=34), junipers, candles, incense lit (n=56), windows (n=72) and doors (n=38) opening for ventilation occurred during the real-time measurements (Table 7).

Table 7: Comparison of indoor PM2.5 concentrations by influencing factors.

Influencing factors	**Frequency**	**N**	**%**	**PM2.5 (µg/m^3)**
Frequency of coal use	1 times-2 times	94	47.9	107.1
	3 times-4 times	89	45.4	98.5
	5 times-6 times	13	6.3	118.6
	Total	196	100	104.4
Smoking frequency	Once	14	41.1	120.5
	2 times-3 times	15	44.1	131.9
	More than 3 times	5	14.8	162.1
	Total	34	100	137.3
Juniper, candles and incense lighting frequency	Once	49	87.5	132.8
	2 times	7	12.5	83.4
	Total	56	100	128.5
Frequency of opening the windows to ventilate	Once	49	68	111.2
	2 times	18	25	82.8
	3 times	5	7	101.3

	Total	72	100	106.5
Frequency of opening the doors to ventilate	Once	28	73.6	132.7
	2 times	8	21	111.3
	3 times	2	5.4	119.6
	Total	38	100	129.3

If a household member smoked in a ger, house or apartment, indoor PM2.5 concentration was measured as 151.4 μg/m^3, which was 58.4 μg/m^3 higher (p=0.0001) than in non-smoking households (93.0 μg/m^3). If the burning fuel frequency increases by one a day, indoor PM2.5 concentration increases by 4.3 μg/m^3 (p=0.385). Characterization of gas pollutants in gers and houses.

Results of carbon monoxide measurements using passive detector tubes: The mean indoor carbon monoxide concentration was 17.6 μg/m^3 ± 9.2 mg/m^3 (min 0.5 mg/m^3, max 38.8 mg/m^3). Indoor 24-hour average carbon monoxide concentrations were measured higher in houses (20.2 μg/m^3 ± 9.3 mg/m^3) as compared with gers (14.4 μg/m^3 ± 8.1 mg/m^3). Particularly, high concentrations of carbon monoxide were observed in households of Songinokhairkhan district (19.9 mg/m^3), whereas lower concentrations were observed in Bayanzurkh district (14.1 mg/m^3), respectively. The carbon monoxide concentration tends to increase (19.2 mg/m^3) as the dwelling volume increases indicating a positive relationship between these two factors.

In terms of heating type, carbon monoxide concentration was higher (20.1 mg/m^3) in households with traditional stoves; while it was measured lower (15.5 μg/m^3-16.5 mg/m^3) in households with improved stoves and heat only boilers (Table 8).

Table 8: Comparison of indoor carbon monoxide concentrations by influencing factors, mg/m^3.

Influencing factors	N	%	Mean	Standard deviation	Min	Max	P-value
Dwelling type							
Gers	45	45	14.4	8.1	1.6	38.8	0.0015
Houses	55	55	20.2	9.3	0.5	36.4	
Total	100	100	17.6	9.2	0.5	38.8	
District							
Bayanzurkh	24	24	14.1	8	2.4	34.8	0.16
Sukhbaatar	28	28	18.3	6	3.6	29.1	
Songinokhairkhan	25	25	19.9	10.7	0.5	38.8	
Khan-Uul	23	23	17.7	11.3	1.6	33.6	
Total	100	100	17.6	9.2	0.5	38.8	
Dwelling volume, m^3							
Up to 45	46	48	14.6	7.9	1.6	38.8	0.0131
45-80	20	21	20.8	8.7	2.4	34	
Above 80	30	31	19.2	9.7	1.9	34.8	
Total	96	100	17.3	8.9	1.6	38.8	

Heating type							
Traditional stove	43	43	20.1	10.2	1.9	38.8	0.061
Improved stove	49	49	15.5	8.1	0.5	31.6	
Heat only boilers, electric heater	8	8	16.5	8.2	3.4	25.2	
Total	100	100	17.6	9.2	0.5	38.8	

Household stoves and chimney aspects had been assessed and examined with the carbon monoxide concentrations. These included the following 9 criteria: "Whether the stove or wall was perforated or broken", "whether the stove and chimney were properly connected", "whether the stove was ventilated enough", "whether the chimney was closed before the complete combustion of fuel", "whether the stove's air supply valve was closed", "whether there was a tall building near the dwelling (within 6 meters)", "whether the stove carrier was full of ashes", "whether there was a cap on top of the chimney", and "whether the chimney is lower than the rafter span". According to this assessment, if there is a point (a risk of carbon monoxide leakage) increment by any risk, indoor carbon monoxide concentration is likely to increase by 2 mg/m^3 ($p=0.012$).

Results of carbon monoxide concentrations using real-time measurements: Carbon monoxide level was about 2.7 mg/m^3 on average (n=63) in 2019 using real-time instrument (Q-Track). It was measured as 8.6 mg/m^3 on average (n=15) in 2020 using different type of real-time measurement (Track Red).

Results of sulfur dioxide measurements using passive detector tubes: Sulfur dioxide was measured for 24 hours using passive detector tubes in 100 households, however, none of the measurements did not reach tube limit of detection which is 560 μg/m^3. Thus, we did not include it in further analysis.

DISCUSSION

The 24 h average indoor PM2.5 concentration was 98.2 μg/m^3 ± 78.2 μg/m^3 in our study, while Enkhjargal A, et al., study result has shown that indoor PM2.5 concentration as 71.53 μg/m^3 ± 67.32 μg/m^3 or less. In this study, the lowest PM2.5 concentration was measured in apartments (61 μg/m^3 ± 50 μg/m^3) while the highest concentration was in houses with stoves (150.2 μg/m^3 ± 116.6 μg/m^3), whereas in Enkhjargal A, et al., study the lowest concentration was measured in apartments (42.94 μg/m^3 ± 16.77 μg/m^3) and the highest was measured in gers (91.98 μg/m^3 ± 87.89 μg/m^3) with traditional stoves. Even though we found similar patterns by dwelling types for both studies, it was differed by the pollutant concentrations. This can be explained by the diverse measurement period since we conducted our study in January and February whereas Enkhjargal A, et al., measured it in March.

The highest PM2.5 concentrations were measured in Bayanzurkh (120.7 μg/m^3) and Songinokhairkhan (105.5 μg/m^3) districts which might be explained by the crowded ger areas combustion in winter time and the high level of outdoor air pollution. Outdoor air is more polluted in these districts according to the government fixed-site monitoring stations data. In Sukhbaatar (has high density of ger area) district, however, indoor air quality was similar with Khan-Uul district, which is less polluted area, and this could be affected by the wind directions. During our measurement period, winds were mainly directed from the north to the south, which likely lead to dispersion and reduction of outdoor air pollution in that area.

PM2.5 concentrations were measured as 150.2 μg/m^3 in gers with traditional stoves and 81.2 μg/m^3 in gers with improved stoves on average, respectively. As compared with improved stoves, any stove damage or pollutant leakage from the stove can occur more frequently which then leads to higher concentrations of PM2.5 in gers with traditional stoves. Moreover, improved fuels might be designed for improved stoves with better enclose.

A comparative study between households who use electric heaters and those who use traditional stoves had been conducted by school of public health, MNUMS in winter 2018. The mean PM2.5 concentration was 91.5 μg/m^3 in households with electric heaters and 133.3 μg/m^3 in households with stoves. This was consistent with our result as the PM2.5 concentrations were 78.4 μg/m^3 in households with electric heaters/heat only boilers and 111.2 μg/m^3 in households with stoves in our study.

In terms of stove types, the mean 24 h PM2.5 concentration was 150.2 μg/m^3 ± 116.6 μg/m^3 in gers with traditional stoves, 128.4 μg/m^3 ± 96.1 μg/m^3 in houses with traditional stoves, 81.2 μg/m^3 ± 62.5 μg/m^3 in gers with improved stoves (such as Dul, Ulzii, Khas, Golomt and Ilch) and 86.3 μg/m^3 ± 56.8 μg/m^3 in houses with improved stoves in our study, respectively. According to the measurement results which conducted by Millennium Challenge Account (MCA) stove project, raw coal combustion period, PM2.5 concentrations were measured as 170 μg/m^3 ± 120 μg/m^3 at night time in households with traditional stoves, 160 μg/m^3 ± 80 μg/m^3 in households with Ulzii stoves and 130 ± 90 μg/m^3 in households with Dul stoves, which almost doubles our measurement results. The implications of this can be the measurement time (night time only) and the period of raw, unprocessed coal combustion.

In the MCA study, the average concentration of PM2.5 was 107.0 μg/m^3 in gers and 118.3 μg/m^3 in houses with heat only boilers who use semi-coked coal. In our study, the mean PM2.5 concentration was 78.4 μg/m^3 in households with either electric heaters or heat only boilers which indicates the difference in emission between raw coal and improved fuel.

Buyantushig B et al., study results showed that the average 24 hours PM2.5 concentration was 28.25 μg/m^3, 27.97 μg/m^3 and 37.46 μg/m^3 in apartments with less than 100 m^3, 101 m^3-200 m^3 and above 200 m^3 volume, respectively. These concentrations were 2 times-3 times lower than our measurement results in apartments. They used real-time instruments and recruited households from Sukhbaatar district only, whereas we used weighing method to characterize indoor PM2.5 concentration. Discordantly, PM2.5 concentration had positive relationship with the dwelling volume in their study while it was negative in our measurements. Buyantushig B, et al. found 2 peaks, in the morning (0900-1200) and in the evening (2100-2300) using Dylos DC1700, which is consistent with the peak hours that we observed. Since the peak hours for indoor PM2.5 concentration using real-time instrument were similar with the outdoor air pollution peak hours (0800-1200 in the morning and 1800-2000 in the evening), it is reasonable to assume that outdoor air pollution infiltrates into indoor environment at some point regardless of the dwelling type.

Allen, et al. had reported that the average annual concentration of PM2.5 in apartments was 34.27 μg/m^3 while it is increased to 68.26 μg/m^3 in winter time. These concentrations were relatively low compared to outdoor PM2.5 concentrations of annual, in winter time and ger area as 75 μg/m^3, 148 μg/m^3 and 250 μg/m^3, respectively. This approves that outdoor air is more polluted than indoor environment. Furthermore, PM2.5 concentrations were peaked up at 0700-0900 in the morning and at 2100-2300 in the evening, which overlaps with our diurnal results at some points. It also highlights the infiltration of outdoor air pollution. In our study, PM2.5 concentration was relatively low in the late evening which could be associated with the instrument effect and the various hours of fuel combustion in households. As for FHCs, PM2.5 concentrations were measured relatively low concentration possibly because of the instrument was switched to off or was unplugged from power supplies during the measurement.

Lim, et al. used a Dylos light scattering instrument for 24 hours and found that PM2.5 concentrations were measured as 203.9 μg/m^3 ± 195.1 μg/m^3 in gers with traditional stoves, 257.5 μg/m^3 ± 204.4 μg/m^3 in houses with improved stoves, respectively. These concentrations were higher than our results (150 μg/m^3 ± 116 μg/m^3 and 81 μg/m^3 ± 62 μg/m^3, respectively) which can be explained by sample size as they recruited only 60 households from Chingeltei district and the difference between measurement methods and fuel types at that time.

Dylos DC1700 real-time instrument uses a light scattering method to count particles in a volume of 1 ft 3 (approximately 30 cm^3). The instrument counts all objects (particles, bacteria, water droplets) larger than 0.5 microns and 2.5 microns in diameter. Thus, it is recommended in scholarly articles that the Dylos DC1700 and other light scattering instruments should be used to characterize the time variations of airborne particles. In apartments we used Dylos DC1700 only and it was combined with the gravimetric method in gers and houses measurements. PM2.5 concentrations varied significantly in 24 hours Dylos measurement depended on influencing factors such as the start time of fuel combustion, duration of combustion, indoor smoking, and opening of doors or windows for ventilation.

There was a moderate correlation (r=0.51) between real-time measurement and weighing method implying that the real-time measurement is not accurate enough. In the UGAAR study conducted by Barn, et al. the 7 days geometric mean PM2.5 concentration was 47.9 μg/m^3 in apartments using the Dylos DC1700 instrument, while the 24 h arithmetic mean PM2.5 concentration was 61 μg/m^3 in our study which is 13.1 μg/m^3 higher than their results. This difference may be due to the sample size since they recruited 540 households from Sukhbaatar district only, while we included households of Bayanzurkh and Songinokhairkhan districts with relatively small sample size (n=35) in our study.

Previously in winter (Jan-Feb) 2019, the mean 7 hours-8 hours PM2.5 concentration was 176.1 μg/m^3 as reported by the "indoor air quality study" which was conducted by school of public health, MNUMS. When we reconducted PM2.5 measurements in 2020, in relevance to the raw coal use ban, the mean 8-h PM2.5 concentration was 105.7 μg/m^3 suggesting the reduction of PM2.5 by 71 μg/m^3 which is approximately 40%. The main influencing factors for this reduction may include use of improved fuel, meteorological factors such as air temperature during the measurement periods and less frequency of burning improved fuels because of its heat efficiency.

Luke Clancy, et al., has reported that the average black smoke concentrations were declined by 35.6 μg/m^3 (70%) after the ban on coal sales in Dublin. Consequently, adjusted non-trauma death rate was decreased by 5.7% (95% Cl 4–7, p<0.0001), respiratory deaths by 15.5% (12–19, p<0.0001), and cardiovascular deaths by 10.3% (8–13, p<0.0001). Respiratory and cardiovascular standardized death rates fell coincidently with the ban on coal sales. About 116 respiratory premature deaths and 243 cardiovascular premature deaths had been prevented per year in Dublin since the coal ban. Thus, there is a need to study if the morbidity and mortality of the population have decreased regarding the use of improved fuels.

According to Undarmaa E, et al., study, indoor PM2.5 concentration was measured as 52.8 μg/m^3 which is relatively lower than our study results of 61 μg/m^3. This may be due to the fact that Undarmaa, et al., had measured PM2.5 concentration for 6 hours only using a different type of instrument (SidePak AM510) in households of the Zaisan area in Khan-Uul district which has relatively low level of outdoor air pollution.

Since the use of “good fuel” from winter of 2020, the average concentration of PM2.5 is 98.2 μg/m^3 in gers which is 4 times higher than the WHO air quality recommendation of 25 μg/m^3 and as twice as high the MNS 4585:2016 standard value of 50 μg/m^3, respectively. Compared to the WHO air quality guidelines (25 μg/m^3 for 24 hours) and MNS 4585:2016 air quality standard (50 μg/m^3), PM2.5 concentration was exceeded in 95% and 75% in gers, whereas it is exceeded in 93% and 72% in the houses, respectively. Although PM2.5 concentration is relatively low in apartments, 58% was still exceeded the MNS air quality standard.

As for outdoor air quality, ban on the consumption of raw coal has led to an apparent declining pattern in November 2019-February 2020 compared to the previous years. This is also consistent with our indoor air measurement results since there is a linkage between outdoor and indoor air quality.

Even though the usage of improved fuel is enhancing indoor air quality and reducing particle pollution, further measures should be taken to meet standard levels.

We characterized the 24 hours concentrations of carbon monoxide in the indoor environment and compared it with the WHO recommended level which is 7 mg/m^3 for 24 hours. Since there is no existing indoor air quality standard for carbon monoxide 24 hours concentrations in Mongolia, we compared it with the WHO guidelines for indoor air quality.

In a total of 100 households (45 gers, 55 houses), the average 24 hours carbon monoxide concentration was 17.6 mg/m^3, which is approximately 2.5 times higher than the WHO indoor air quality recommendations. We used a high-precision absorbent tube to characterize carbon monoxide in the households. There is a need to increase the sample size and conduct a comprehensive study to characterize carbon monoxide concentrations in the future. In addition, it is necessary to raise public awareness on the prevention of carbon monoxide poisoning in indoor environments.

Previously in 2019, the average indoor carbon monoxide concentration was 2.7 mg/m^3 in 63 households, while it was 8.6 mg/m^3 on average in 15 households in 2020 using a different type of real-time instrument. We used a real-time "Q-track" instrument in 2019 and "red track" instrument in 2020, respectively. The highest indoor carbon monoxide concentration (19.9 mg/m^3) was measured in Songinokhairkhan district which may be linked to the large number of ger/house households and high level of outdoor air pollution.

The indoor carbon monoxide concentrations were relatively low in gers compared to the house since ger can be ventilated well through the doors and walls. The carbon monoxide concentration tended to increase as the volume of households increases possibly due to the fact that ger has a less volume than houses.

There is sufficient evidence that indoor carbon monoxide levels of 15 to 20 mg/m^3 may cause cardiovascular and mental changes in vulnerable populations over a long period of time. Short-term exposure to this amount of carbon monoxide can cause headaches, shortness of breath, and drowsiness.

Metropolitan Professional Inspection Department (MPID) had started an intervention to install carbon monoxide detectors in every household since several carbon monoxide poisoning cases have been reported during winter of 2020 in Ulaanbaatar. This device is designed for an audible alarm if the carbon monoxide concentration exceeds 80 mg/m^3. Since the maximum concentration of carbon monoxide in our study households was 45 mg/m^3, none of the study households had given the alarm.

In terms of the heating type, indoor concentrations of carbon monoxide in households with traditional stoves were 20.1 mg/m^3 on average which is slightly higher than households with improved stoves, heat only boilers, and electric heater (15.5 $\mu g/m^3$-16.5 mg/m^3) implying that traditional stoves, chimneys and other stove conditions can lead to the carbon monoxide emission.

The MPID had provided recommendations for citizens on the reduction of carbon monoxide emissions in gers and houses in accordance with the household heating and stove management. The recommendation had included following 9 criteria: "Whether the stove or wall is perforated or broken", "whether the stove and chimney are properly connected", "whether the stove is ventilated enough", "whether the chimney is closed before the complete combustion of fuel", "whether the stove's air supply valve is closed", "whether there is a tall building near the dwelling (within 6 meters)", "whether the stove carrier is full of ashes", "whether there is a cap on top of the chimney", and "whether the chimney is lower than the rafter span". Assuming these 9 points assessments, if there is one-point (a single risk of carbon monoxide leakage) increment, indoor carbon monoxide concentration was tended to increase by 2 mg/m^3. This suggests that high concentration of indoor carbon monoxide can be associated with not only fuel type but also household firing behavior and stove/chimney conditions. In order to reduce the concentration of carbon monoxide in gers and houses, it is necessary to monitor above influencing factors and run it as a good practice.

It is essential to study carbon monoxide poisoning and its levels in gers and houses with further immediate actions if the concentration is high. Long-term measurements of indoor carbon monoxide concentration covering spring and autumn period can prevent further adverse consequences.

CONCLUSION

The average 24 hours concentration of PM2.5 is 102.7 $\mu g/m^3$ in total households, which is 2.1 times higher than the Mongolian air quality standard MNS 4585:2016. Particulate matter pollution varies significantly by dwelling and heating types. The concentration of indoor PM2.5 is relatively high (128.4 $\mu g/m^3$-150.2 $\mu g/m^3$) in gers and houses with traditional stoves, whereas it is lower (81.2 $\mu g/m^3$-86.3 $\mu g/m^3$) in gers and houses with improved stoves.

PM2.5 concentrations vary diurnally in gers, houses and apartments with peak concentrations from 07:00 to 11:00 in the morning (68 $\mu g/m^3$-96 $\mu g/m^3$) and from 18:00 to 20:00 in the evening (71 $\mu g/m^3$-85.5 $\mu g/m^3$). The peak PM2.5 concentration is occurred between 09:00 and 12:00 in the afternoon in FHCs. PM2.5 concentrations are varied by district, with relatively low concentrations observed in Khan-Uul and Sukhbaatar districts (87.9 $\mu g/m^3$) as compared to households in Songinokhairkhan and Bayanzurkh districts (108.1 $\mu g/m^3$).

Compared to the winter of 2019 (176.1 μg/m^3), the mean concentration of PM2.5 was measured as 105.7 μg/m^3 (40% lower) in gers/houses who used refined/improved "good" fuel in Jan-Feb of 2020. Thus, indoor PM2.5 concentration in gers and houses had decreased significantly ($p<0.05$) in winter when improved fuels usage was introduced.

CONFLICT OF INTEREST

The authors have no competing interests.

AUTHOR CONTRIBUTION

Jargalsaikhan Galsuren: Data curation, formal analysis visualization, writing, original draf; Enkhjargal Gombojav: Conceptualization, methodology, writing, review and editing; Buyantushig Boldbaatar: Data curation, formal analysis, investigation; Nansalmaa Munkhtur: Investigation; Bayarjargal Namnan: Investigation; Urangua Lkhagvatseren: Investigation; Davaalkham Dambadarjaa: Funding acquisition; resources, supervision, project administration, writing, review and editing.

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DATA AVAILABILITY

Original data from this study is freely available upon contact.

ETHICAL CONSIDERATIONS

- Residents of gers, houses and apartments were given the detailed information on study purpose, objectives, importance and subsequent use of the study results as for research and official purposes through an 'informed consent form'. Participants who consented only were recruited in the study.
- We obtained an ethical approval from the ethical review board of the MNUMS on January, 2020.

ETHICAL APPROVAL

Primary data collections were conducted in accordance with principles for human experimentation as defined in the declaration of Helsinki and international conference on harmonization good clinical practice guidelines and approved by the institutional review board of Mongolian national university of medical sciences.

INFORMED CONSENT

Each study participant had read and signed in informed consent form after they were told of the potential risks and benefits.

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