Elemental Composition of Indoor Particulate Matter in Response to Heating Facility at Sakaka City, Saudi Arabia

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Abstract. Indoor and outdoor airborne particulate matter (PM$_{10}$ and PM$_{2.5}$) were sampled from homes with different heating facilities, located at Sakaka city, northern of Saudi Arabia during winter season. Elemental composition of PM$_{10}$ and PM$_{2.5}$ samples, including Al, Ba, Be, Ca, Cd, Co, Cr, Fe, Ga, K, Li, Mg, Mn, Na, Ni, Pb, Se, Te and Tl, were analyzed using inductively coupled plasma-mass spectroscopy (ICP-MS). Black carbon (BC) was also measured using EEL-type Smoke Stain Reflectometer. Results showed that the highest indoor concentration PM$_{2.5}$ (541.67 µg m$^{-3}$) and PM$_{10}$ (1201.39 µg m$^{-3}$) were found at homes using wood burning as heating facility. The most dominant metals were Na, Fe and Al in the investigated PM$_{2.5}$ and PM$_{10}$ samples. The highest concentrations of black carbon were found in homes using wood burning as heating facility. For similar homes in heating facilities, we can deduce that by increasing the number of smoking persons the value of BC increased.

Keywords: PM2.5 and PM10, Indoor, Outdoor, Elemental composition, Black carbon, heating facilities, Sakaka, Saudi Arabia.

Introduction

People spend most of their time (60-90%) indoors (Nastov, et al., 2003; Yip et al., 2004). Therefore, good indoor air quality is very important to us. Children and women spend most of their time in indoor environments and are more exposed to pollution indoors than outdoors. Currently, there has been a rapid expansion of interest in indoor air quality and its contribution to total human exposure to air pollutants (Schneider, et al., 2003; Conner and Williams, 2004).

Each indoor micro-environment is uniquely characterized and determined by the local outdoor air, specific building characteristics and indoor activities (Stranger, et al., 2007). Consequently, each individual’s personal exposure will be determined by a combination of the local outdoor pollutant levels and the different indoor micro-environments to which s/he is exposed to, and their residence time. There are hundreds of pollutants which affect indoor air quality and thousands of sources (Hays, et al., 1995, Chencen, et al., 2016). In homes, there are many indoor sources of particulate and gaseous air pollutants, including combustion processes, clothing fibers, building materials and furnishings, wet or damp carpet, cabinetry or furniture made of
certain pressed wood products, products for household cleaning and maintenance, personal care or hobbies detergent solution and pesticides, central heating and cooling systems and humidification devices, and outdoor sources (U.S.EPA, 1996; Abdul-Wahab, 2006, Aneesa, et al., 2015).

Several studies have shown the impact of outdoor air on the indoor environment (Srivastava and Jain, 2003, Nastov et al., 2003, Anna et al., 2014, Reto et al., 2015, Peiyao et al., 2015). In many studies, it has been shown that outdoor and indoor pollutant concentration levels correlate with each other (Paschold, et al., 2003; Bae, et al., 2004; Kornartit, et al., 2010). However, there are cases where a considerable amount of air pollution might have originated from indoor activities alone (Chao and Wong, 2002; Branis, et al., 2005). In addition, the air within the buildings can be more seriously polluted than the outdoor air in even the largest and most industrialized city (Lee, et al., 2002).

There is a lack of information on the indoor levels of particulate PM$_{2.5}$ and PM$_{10}$ and their chemical composition in homes in Saudi Arabia. Therefore, the present study aimed to fill the above mentioned gap of knowledge by evaluating the indoor concentrations, elemental composition and black carbon of PM$_{2.5}$ and PM$_{10}$ in homes with different heating facilities at Sakaka city, Saudi Arabia, and to compare these concentrations with ambient air levels. In addition, the factors that had an effect on the indoor levels PM2.5 and PM10 and their chemical composition were measured.

Materials and Methods

Study area

Sakaka is located at the north of Saudi Arabia kingdom, with the latitude as N 59’ 29’ and longitude as E 40’12’. Its area and population are 8053 km$^2$ and 242,813, respectively. Most of commercial activities are concentrated in the city center which defined as residential and government working area. All the investigated sites were near this area as shown in Figure (1). In winter of 2014-2015, the average relative humidity and wind speed were 40.7% and 12 km/h, respectively. Indoors and outdoors particulate PM$_{10}$ and PM$_{2.5}$ were collected at different homes using different heating facilities (Table 1) during winter season (December 2014-March 2015).

![Fig. 1. Selected homes at Sakaka city.](image)
Table 1. The used home heating facilities at the different investigated homes.

| Home | Home heating facility         |
|------|-------------------------------|
| 1    | Air conditioner               |
| 2    | Wood fire                     |
| 3    | Gas heater & Air conditioner  |
| 4    | Electrical heater & Air conditioner |
| 5    | Air conditioner               |
| 6    | Wood fire                     |
| 7    | absent                        |
| 8    | absent                        |

**Sampling**

Particulate PM$_{2.5}$ and PM$_{10}$ samples were collected on membrane quartz filters 37 mm in diameter, using calibrated pump (Leland Legacy Sample Pump from SKC) with PM$_{2.5}$ and PM$_{10}$ inlets operated at constant flow rate (10l/min.) and programmed to collect 24h samples. The filters were weighed before sampling on an analytical balance. At the end of sampling period, the filters were reweighed to calculate weight and concentrations of particulates in air (µg/m$^3$).

**Elemental Analysis**

All filters were digested in 5ml concentrated nitric acid and 2ml of hydrochloric acid at 120°-200° C using sand bath and then diluted to 5ml (Fernandez, et al., 2000). The extracted solution was filtered, using a Whatman no 41 filter, completed to 5 ml with distilled-deionized water. After digestion, an inductively coupled plasma atomic emission spectrometer (Shimadzu ICPE-9000) was used to measure the trace metal concentration including Al, Ba, Be, Ca, Cd, Co, Cr, Fe, Ga, K, Li, Mg, Mn, Na, Ni, Pb, Se, Te and Tl. The background contamination was routinely monitored using operational blanks (unexposed filters) that were processed simultaneously with field samples.

**Black carbon**

Black carbon (BC) was measured using EEL-type Smoke Stain Reflectometer (Diffusion Systems, Ltd). Secondary standards of known black carbon concentrations were used to calibrate the reflectometer (Biswas, et al., 2003). The concentrations are defined based on the amount of reflected light that is absorbed by the filter sample and an assumed mass absorption coefficient. It is related to the concentration of light absorbing carbon through standards of carbon with a known areal density.

**Results and discussion**

**Particulate PM$_{2.5}$ and PM$_{10}$ concentrations**

Indoor concentrations of PM$_{2.5}$ and PM$_{10}$ in different homes are illustrated in Figures (2&3). The highest concentrations were 541.67 µg m$^{-3}$ and 201.39 µg m$^{-3}$ for PM$_{2.5}$ and PM$_{10}$, respectively. These highest concentrations were recorded at homes that use wood burning as heating facility (location 2&6 at Figure 1).

The indoor guidelines for PM$_{2.5}$ are variable within the few countries that already defined such regulation (Stranger, et al., 2007). The limit value varies between 15 mg m$^{-3}$ (averaged over one year) in Belgium (Decree of The Flemish Government, 2004), 25 mg m$^{-3}$ (averaged over 8 h) in Portugal (Portaria n.° 353-A/2013 de 4 de Dezembro, 2013) and 40 mg m$^{-3}$ (averaged over 1 h) in Canada.

The levels of PM$_{2.5}$ in the present study were higher than that reported in literature. John, et al. (2007) recorded mean concentrations of PM$_{2.5}$ at urban, suburban and rural area in the states to be 16, 17 and 16 µg m$^{-3}$. Another study was conducted at Antwerp, Belgium and showed that the average indoor PM$_{2.5}$ levels ranged from 54 to 72 µg m$^{-3}$, on 12 h samples (Stranger, et al., 2008). In Stockholm, a study of the chemical characterization of PM$_{2.5}$ concluded that PM$_{2.5}$ concentrations in indoors ranged from 3.9 to 19 µg m$^{-3}$, on 6 h samples (Molnár, et al., 2007), Fromme, et al. (2008) focused his study
in the particulate matter and found mean PM$_{2.5}$ indoor values of 37 $\mu$g m$^{-3}$, (5 h per day).

The higher concentrations of PM$_{2.5}$ measured in the present study can be associated with the existence of wood burning process used as heating facility in homes (sites 2&6). In fact, the wood burning process is the main distinguishable factor and it has been reported that the biomass combustion is a major source of PM$_{2.5}$ (Reisen, et al., 2013; Molnár, et al., 2005).

The outdoor concentrations of PM$_{10}$ and PM$_{2.5}$ monitored at the selected homes are presented graphically in Figures (2&3). The highest outdoor concentrations of PM2.5 and PM10 were recorded at home 5 during dust storm. They were 368.06 $\mu$g m$^{-3}$ for PM$_{2.5}$ and 437.50 $\mu$g m$^{-3}$ for PM$_{10}$. Sakaka city is exposed to bouts of dust storm that lead to increase the levels of particulate matter fractions (PM$_{2.5}$ and PM$_{10}$) in the atmosphere (Basheer and Naif, 2015).

The concentrations of outdoor PM$_{2.5}$ and PM$_{10}$ in the present study exceeded World Health Organization for both PM$_{2.5}$ and PM$_{10}$ daily averages of 25 and 50 $\mu$g m$^{-3}$, respectively. The concentration of PM$_{10}$ exceeded the European Union Air Quality Standard for daily average of 50 $\mu$g m$^{-3}$ in all samples. However, in comparison with U.S. 24–hr average standards, only 25% of PM$_{10}$ samples exceeded the standard of 150 $\mu$g m$^{-3}$, and all of PM$_{2.5}$ samples exceeded the standard of 65 $\mu$g m$^{-3}$. These results clearly indicated that the airborne particulate pollution has been high in Sakaka.

![Fig. 2. Indoor and outdoor concentrations of PM$_{2.5}$ at homes in Sakaka city during the period of study.](image)

![Fig. 3. Indoor and outdoor concentrations of PM$_{10}$ at homes in Sakaka city during the period of study.](image)
Indoor/outdoor PM$_{2.5}$ and PM$_{10}$ concentration ratios

Indoor/Outdoor concentration ratios (I/O) for PM$_{2.5}$ and PM$_{10}$ at each selected home were calculated and presented graphically in Figure (4). From this figure, it is clear that the indoor PM$_{2.5}$ and PM$_{10}$ concentrations were higher than the corresponding levels outdoors at homes (2 & 6) where wood fire facility is used. Many studies have had contrasting results, finding low or high correlations between indoor and outdoor pollutant concentrations when sampling inside and directly outside of homes (Adgate et al., 2002; Ramachandran, et al., 2000). Levy et al. (2002) and Morawska et al. (2001) identified moderate to high (I/O) pollutant ratios.

Elemental concentration of PM$_{2.5}$ and PM$_{10}$

The trace element concentrations for indoor PM$_{2.5}$ and PM$_{10}$ fractions are shown in Table (2). The values were in the order as Na > Co > Se > Al > Fe > Ni > Li > Te > K > Ga > Cd > Mn > Pb > Be=Ti > Ba > Cr > Mg > Ca for PM$_{2.5}$ fraction, whereas the order was Mn > K > Na > Co > Se > Ca > Fe > Mg > Ni > Al > Li > Te > Tl > Ga > Cd > Pb > Ba > Be > Cr for PM$_{2.5}$. Na was the highest measured concentration (5375 ng/m$^3$) in the investigated PM$_{2.5}$ samples, whereas K was the highest measured concentration (13479 ng/m$^3$) for PM$_{10}$ samples.

With regard to the outdoor, the trace elements concentrations for PM$_{2.5}$ and PM$_{10}$ fractions are showed in Table (3). For PM$_{2.5}$ fraction, the values were in the order as Fe > Al > Na > Te > K > Mg > Ca > Ga > Mn > Tl > Se > Ba > Pb > Cr > Ni > Co > Li > Be, Cd. For PM$_{10}$, the order was Na > Fe > Al > Ca > Te > Mg > K > Mn > Tl > Ga > Se > Ba > Ni > Pb > Cr > Co > Li, Be, Cd. Among of these trace elements, heavy metals were of major concern because of their toxicity. Heavy metals could enter into human body via directly inhalation, affecting central nervous system and acting as cofactors in other diseases, especially for young children who were more sensitive than adults. For example, lead was related to kidney disease, peripheral neuropathy and encephalopathy; kidney was the main target for Cd and it can cause osteomalacia or osteoporosis; Mn, Co, Cu and Pb were initiators or promotors of carcinogenic activities.
in animals; Cr was neurological, renal and developmental toxicant at certain concentrations (Gupta, et al., 2007).

In the present study, Fe was one of the major contributors to the sampled PM\textsubscript{2.5}. In Stockholm (Molnár, et al., 2007), a study of the chemical characterization of PM\textsubscript{2.5} concluded that Fe and K were among the elements with the largest contribution to the aerosol.

**Black carbon**

Black carbon is a good indicator of combustion-related air pollution. The concentrations of black carbon in the present study are listed in Table (4). The high concentration of BC was in homes (2&6) where wood burning was used as the heating facility. For similar homes in heating facilities (1&5) we can deduce that by increasing the number of smoking persons the value of BC increased. Effects related with BC emissions included oxidative stress, inflammation, lipid peroxidation and atherosclerosis, change in heart rate variability, arrhythmias, ST-segment depression (heart function), and changes in vascular function (such as blood pressure) (Grahame & Schlesinger, 2010).

### Table 2. Elemental concentrations in indoor samples within PM\textsubscript{2.5} and PM\textsubscript{10} fractions (ng/m\textsuperscript{3}).

| Site | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | M | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | M |
|------|--------|--------|--------|--------|--------|--------|--------|--------|---|--------|--------|--------|--------|--------|--------|--------|--------|---|
| Al   | ND     | 447.1  | ND     | ND     | ND     | 1174   | 284    | 54.2   | 244.9 | 1609   | 830.4  | 81.7   | ND     | 824.2  | 72.5   | ND     | ND     | 427.2 |
| Ba   | ND     | ND     | ND     | ND     | ND     | ND     | 15.0   | ND     | 1.9 | 31.2   | 4.7    | 20     | ND     | ND     | ND     | ND     | ND     | 7.0   |
| Be   | ND     | ND     | 0.1    | ND     | ND     | 19.3   | 1.5    | ND     | 2.6 | 1.0    | 0.2    | 7.3    | 1.2    | 12.5   | 6.2    | ND     | ND     | 3.6   |
| Ca   | ND     | ND     | ND     | ND     | ND     | ND     | ND     | ND     | 0.0 | 3183   | 395.8  | ND     | ND     | ND     | ND     | ND     | ND     | 447.4 |
| Cd   | 9.8    | 0.4    | ND     | ND     | ND     | 89.6   | 0.1    | ND     | 12.5 | 2.5    | 8.3    | 28.8   | ND     | 64.6   | 63.3   | ND     | ND     | 20.9  |
| Co   | ND     | 1.5    | ND     | ND     | ND     | ND     | ND     | ND     | 1037.7 | 5.7    | 1.0    | 1570   | ND     | 6133   | 3087   | ND     | ND     | 1349.6 |
| Cr   | ND     | ND     | ND     | ND     | ND     | ND     | ND     | 8.1    | ND     | 1.0    | 19.1   | 4.9    | ND     | 2.4    | ND     | ND     | 1.4    | ND     | 3.5   |
| Fe   | ND     | 865    | 12.5   | 40.8   | ND     | ND     | 632    | 143    | 211.7 | 1377   | 1582   | ND     | ND     | ND     | 0.1    | 302    | 186    | 430.9 |
| Ga   | ND     | ND     | 2.75   | 16.8   | ND     | 8.3    | 223    | 31.8   | 35.3 | ND     | ND     | 2.20   | ND     | 5.5    | 4.6    | 78.0   | 88.8   | 22.4  |
| K    | ND     | ND     | ND     | ND     | ND     | ND     | 10.5   | 304    | 39.3 | ND     | 13479  | 11.8   | ND     | 20.7   | 15.0   | ND     | ND     | 1690.8 |
| Li   | ND     | 0.8    | ND     | ND     | ND     | ND     | ND     | ND     | 195.5 | 22.9   | ND     | 62.5   | ND     | 1142.9 | 78.8   | ND     | ND     | 163.4 |
| Mg   | ND     | ND     | ND     | ND     | ND     | 0.8    | ND     | ND     | 0.1 | 2191   | ND     | ND     | ND     | 24.3   | ND     | ND     | ND     | 276.9 |
| Mn   | 38.9   | 17.3   | ND     | ND     | ND     | 30.0   | 12.6   | ND     | 12.4 | 66.7   | 34.6   | 69.6   | ND     | 508    | 15041  | 4.6    | ND     | 1965.6 |
| Na   | 21.7   | 2429   | 579.2  | 695    | 420    | 3877   | ND     | 5375   | 1674.6 | ND     | ND     | ND     | 1839   | 305.8  | 2956   | 1839   | 4625   | ND     | 1445.6 |
| Ni   | ND     | ND     | ND     | ND     | ND     | 1650   | 1.3    | ND     | 206.4 | 16.3   | 3.3    | 323    | ND     | 1291   | 504    | ND     | ND     | 267.2 |
| Pb   | ND     | 5.3    | ND     | ND     | ND     | 37.0   | 2.1    | ND     | 5.6 | 31.7   | 7.1    | ND     | ND     | 24.5   | 2.1    | ND     | ND     | 8.2   |
| Se   | 21.7   | 4.6    | ND     | ND     | ND     | 3877   | ND     | ND     | 487.9 | 73.3   | 9.6    | 1839.6 | ND     | 2956.3 | 1839.6 | ND     | ND     | 839.8 |
| Te   | ND     | 662.9  | ND     | ND     | ND     | 412    | 67.9   | 142.9  | 987.9 | 75.8   | ND     | ND     | ND     | ND     | ND     | ND     | ND     | 133.0 |
| Tl   | ND     | 3.3    | ND     | 1.3    | 16.0   | ND     | ND     | 2.6 | 155.0 | 9.2    | 1.2    | ND     | 12     | 3.5    | ND     | ND     | 22.6  |

ND: Not detected result  
M: mean
Table 3. Elemental concentrations in outdoor samples within PM$_{2.5}$ and PM$_{10}$ fractions (ng/m$^3$).

| Site | PM$_{2.5}$ | PM$_{10}$ |
|------|------------|-----------|
|      | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | M  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | M  |
| Al   | 3292| 530| ND | ND | ND | ND | 372| 567| 595.1| 1355| 222| 3.3| ND | ND | ND | 880.4| 951| 426.5|
| Ba   | 9.9 | ND | ND | ND | ND | 7.7| 22.0| 5.0 | 21.2| ND | ND | ND | 7.5| ND | ND | 12.5| 19.5| 6.7 |
| Be   | 0.3 | ND | 0.3| 6.7| ND | ND | ND | 0.9 | ND | ND | ND | ND | 2.4| ND | ND | 0.1 | ND | 1.0 |
| Ca   | 712 | ND | ND | ND | ND | ND | 29.2| 229| 121.3| 1520| ND | ND | ND | ND | ND | 495.8| 550| 320.7|
| Cd   | 1.9 | 0.6| ND | 4.0| ND | ND | ND | 0.4| 0.9 | 1.3 | 0.3| ND | ND | 4.8| ND | ND | 0.8 | 0.8 | 1.0 |
| Co   | 4.7 | 1.8| ND | 5.1| ND | ND | ND | 0.8| 1.6 | 2.5 | 1.1| ND | ND | 5.6| ND | ND | 1.8 | 1.3 | 1.5 |
| Cr   | 20.4| ND | ND | ND | ND | 2.3| 6.5 | 3.7 | 10.0| ND | ND | ND | ND | ND | 5.8 | ND | 6.4 | 2.8 |
| Fe   | 4407| 1019| 50.4| ND | ND | 207| 977 | 1723| 1047.9| 2340| 565 | 240 | ND | ND | 232 | 1748| 1815| 867.5|
| Ga   | 21.8| ND | 18.0| ND | ND | ND | 198| 239| 59.6 | 5.8  | ND | 83.8| ND | ND | ND | 6.0  | ND | 12.0 |
| K    | 1033| ND | ND | ND | ND | ND | ND | 95.8| 141.1| 125 | ND | ND | ND | ND | ND | 225.0| 254 | 75.5 |
| Li   | 3.2 | 0.6| ND | 5.6| ND | ND | ND | ND | 1.2 | 0.5 | 0.5| ND | ND | 6.5| ND | ND | 0.5 | ND | 1.0 |
| Mg   | 1033| ND | ND | ND | ND | ND | ND | ND | 129.1| 325 | ND | ND | ND | ND | ND | 458 | ND | 97.9 |
| Mn   | 69.6| 20.7| ND | ND | ND | ND | 19.3| 27.5| 17.1 | 55.4 | 15.7| 4.1| ND | ND | ND | 39.6 | 43.3| 19.8 |
| Na   | ND  | 2845| 820| ND | 278| 177| ND | ND | 515.0| 6458| 1712| 1358| ND | 251 | 270.0| ND | ND | 1256.1|
| Ni   | 15.7| 0.2| ND | ND | ND | ND | 3.2 | 5.6 | 3.1 | 13.2 | ND | 0.1| ND | ND | 21.6 | 6.1  | 5.1  |
| Pb   | 23.4| 6.8 | ND | ND | ND | ND | 3.3 | 4.2 | 17.4 | 2.8 | ND | ND | ND | 7.1 | ND | 5.8 | 4.1  |
| Se   | 43.3| 4.2 | ND | ND | ND | ND | ND | 3.8 | 7.7 | 35.4 | 1.3 | ND | ND | ND | 19.6 | 12.5 | 8.6  |
| Te   | 271.3| 787 | ND | ND | ND | 23 | 625 | 53.8| 220.0| 154 | 604 | 182 | ND | ND | 75.8 | 106.7| 81.7 | 150.5|
| Tl   | 36.7| 7.1 | 6.7| ND | 24.6| ND | ND | 2.1 | 9.7 | 27.9| ND | ND | ND | 10.4| 35.4 | 15.8 | 9.6 | 12.4 |

ND: Not detected result M: mean

Table 4. Black carbon (BC) concentrations in indoor samples (μg/m$^3$).

| Site | BC | Heating facility             | Number of smokers |
|------|----|------------------------------|-------------------|
| 1    | 5.65| Air conditioner              | zero              |
| 2    | 89.34| Wood fire                    | 2                 |
| 3    | 3.16| Gas heater& Air conditioner  | 4                 |
| 4    | 12.72| Electrical heater& Air conditioner | 2         |
| 5    | 15.56| Air conditioner              | 2                 |
| 6    | 98.65| Wood fire                    | 6                 |
| 7    | 13.27| absent                       | 2                 |
| 8    | 3.16| absent                       | zero              |
Conclusions

Field measurements were conducted to determine the levels of indoor PM$_{2.5}$ and PM$_{10}$ in homes where different heating facilities were used. The elements associated with indoor and outdoor PM$_{2.5}$ and PM$_{10}$ were investigated. Black carbon (BC) was also measured. The most dominant metals were Na, Fe and Al. The highest indoor PM$_{2.5}$ and PM$_{10}$ concentrations were found in homes using wood burning as heating facility. The indoor PM$_{2.5}$ and PM$_{10}$ concentrations were higher than the corresponding levels outdoors at homes where wood fire facility is used.

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المحتوى العنصري للجسيمات العالقة الداخلية نتيجة لوسائل التدفئة المنزلية في مدينة سكاكا، المملكة العربية السعودية

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المستخلص، تم جمع عينات الجسيمات العالقة المحمولة (PM10 و PM2.5) في الهواء الداخلي والخارجي من منازل مختلفة تستخدم وسائل التدفئة، تقع في مدينة سكاكا شمال المملكة، خلال موسم الشتاء. التركيب العنصري لعينات PM2.5 و PM10، بما في ذلك العناصر لم تحللها باستخدام التحليل الطيفي (Inductively Coupled Plasma-mass) (ICP-MS) أيضًا باستخدام (Spectroscopy EEL-type Smoke Stain). وقد تم قياس الكربون الأسود (BC) (BC Reflectometer) و (BC Reflectometer) و (BC Reflectometer) و (BC Reflectometer). وأظهرت النتائج أن أعلى تركيز داخلي (541,777 نانوغرام/الثانية) لـ PM2.5 و PM10 تم رصده في المنازل التي تستخدم الخشب في التدفئة. أظهرت تكيرات المعادن النائمة في الهواء الداخلي أن الصوديوم والكربون والألومينيوم كن الأعلى، لوحظ أن أعلى تركيزات الكربون الأسود وجد في المنازل التي تستخدم الخشب للتدفئة. في المنازل المشابهة في وسائل التدفئة، وجد أن زيادة عدد الأشخاص المدخنين أدى إلى ارتفاع قيمة الكربون الأسود.