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 (PM₁₀ 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 PM₁₀ 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 PM₁₀ (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 PM₁₀ 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, Chenchen, *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 house hold 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 $PM_{2.5}$ and PM_{10} 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 km² 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.

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 PM₁₀ 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 PM₁₀ 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 ($\mu\text{g}/\text{m}^3$).

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 PM₁₀ concentrations

Indoor concentrations of PM_{2.5} and PM₁₀ in different homes are illustrated in Figures (2&3). The highest concentrations were $541.67 \mu\text{g m}^{-3}$ and $201.39 \mu\text{g m}^{-3}$ for PM_{2.5} and PM₁₀, 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.º 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 $16 \mu\text{g m}^{-3}$. Another study was conducted at Antwerp, Belgium and showed that the average indoor PM_{2.5} levels ranged from 54 to $72 \mu\text{g m}^{-3}$, 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 $19 \mu\text{g m}^{-3}$, 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 $PM_{2.5}$ and PM_{10} 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.

Fig. 3. Indoor and outdoor concentrations of PM_{10} at homes in Sakaka city during the period of study.

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.

Fig. 2. Indoor and outdoor concentrations of $PM_{2.5}$ and PM_{10} at homes in Sakaka city during the period of study.

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 $Na > Co > Se > Al > Fe > Ni > Li > Te > K > Ga > Cd > Mn > Pb > Be = Tl > Ba > Cr > Mg > Ca$ 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_{10} . 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_{2.5}. In Stockholm (Molnár, *et al.*, 2007), a study of the chemical characterization of PM_{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_{2.5} and PM₁₀ fractions (ng/m³).

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	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	8300	ND	ND	1037.7	5.7	1.0	1570	ND	6133	3087	ND	ND	1349.6
Cr	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	10.5	304	ND	39.3	ND	13479	11.8	ND	20.7	15.0	ND	ND	1690.8
Li	ND	0.8	ND	ND	ND	1563	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	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	ND	412	67.9	142.9	987.9	75.8	ND	ND	ND	ND	ND	ND	133.0
Tl	ND	3.3	ND	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 PM₁₀ fractions (ng/m³).

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	ND	7.7	22.0	5.0	21.2	ND	ND	ND	ND	ND	12.5	19.5	6.7
Be	0.3	ND	0.3	6.7	ND	ND	ND	ND	0.9	ND	ND	ND	7.5	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	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	5.6	ND	ND	1.8	1.3	1.5
Cr	20.4	ND	ND	ND	ND	ND	2.3	6.5	3.7	10.0	ND	ND	ND	ND	ND	5.8	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	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	ND	0.1	ND	ND	21.6	6.1	5.1
Pb	23.4	6.8	ND	ND	ND	ND	ND	3.3	4.2	17.4	2.8	ND	ND	ND	ND	7.1	5.8	4.1
Se	43.3	14.2	ND	ND	ND	ND	ND	3.8	7.7	35.4	1.3	ND	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/m³).

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 PM₁₀ in homes where different heating facilities were used. The elements associated with indoor and outdoor PM_{2.5} and PM₁₀ were investigated. Black carbon (BC) was also measured. The most dominant metals were Na, Fe and Al. The highest indoor PM_{2.5}, PM₁₀ and BC concentrations were found in homes using wood burning as heating facility. The indoor PM_{2.5} and PM₁₀ concentrations were higher than the corresponding levels outdoors at homes where wood fire facility is used.

References

- Abdul-Wahab, S.A. (2006) Indoor and Outdoor Relationships of Atmospheric Particulates in Oman, *Indoor and Built Environ.*, **15**: 247-255.
- Adgate, J., Ramachandran, G., Pratt, G., Waller, L. and Sexton, K. (2002) Spatial and temporal variability in outdoor, indoor, and personal PM_{2.5} exposure, *Atmos. Environ.*, **36**, p.3255.
- Aneesa, V., Whitney, B., Polite, M. N., Robert, P. G., Peter, D. S. and Heather, J. Z. (2015) Home environment and indoor air pollution exposure in an African birth cohort study, *Science of the Total Environment*, **536**: 362–367.
- Anna, J. B., Agnieszka, K., Rene Van, G., Andrew, B., Gabriela, P., Karolien D., Sanja P. (2014) Composition of PM_{2.5} and PM₁ on high and low pollution event days and its relation to indoor air quality in a home for the elderly, *Science of the Total Environment*, **490**: 134-143.
- Bae, H., Yang, W. and Chung, M. (2004) Indoor and outdoor concentrations of RSP, NO₂ and selected volatile organic compounds at 32 shoe stalls located near busy roadways in Seoul, Korea, *Sci. Total Environ.*, **323**: 99-105.
- Basheer, M. G. and Naif, S. A. (2015) *Dust fall and suspended dust in Sakaka city*, Cultural alsudairy center, 1st ed., 17. (in Arabic).
- Biswas, S.K., Tarafdar, S.A., Islam, A., Khaliquzzaman, M., Tervahattu, H. and Kupiainen, K. (2003) Impact of Unleaded Gasoline Introduction on the Concentration of lead in the Air of Dhaka, Bangladesh, *J. Air Waste Manage. Assoc.*, **53**: 1355–1362.
- Braniš, M., Řezáčová, P. and Domasova, M. (2005) The effect of outdoor air and indoor human activity on mass concentrations of PM₁₀, PM_{2.5}, and PM₁ in a classroom, *Environ. Res.*, **99**: 143–149.
- Chao, C. Y. and Wong, K. K. (2002) Residential indoor PM₁₀ and PM_{2.5} in Hong Kong and the elemental composition, *Atmos Environ.*, **36**: 265-277.
- Chenchen, C., Weidong, C., Min, G., Mili, W., Gang, Y. and Xueyou, S. (2016) Law and features of TVOC and Formaldehyde pollution in urban indoor air, *Atmospheric Environment*, **132**: 85-90.
- Conner, T. L. and Williams, R. W. (2004) Identification of possible sources of particulate matter in the personal cloud using SEM/EDX, *Atmos Environ.*, **38**: 5305-5310.
- Decree of the Flemish government (2004) of 11 June 2004 providing for measures aiming at controlling health risks caused by indoor pollution, *Belg. Off. J.*, 19/10/2004.
- Fernandez, A. J., Ternero, M., Barragán, F. J. and Jiménez, J. C. (2000) *Chemosphere*, **2**, p.123.
- Fromme, H., Diemer, J., Dietrich, S., Cyrus, J., Heinrich, J., Lang, W., Kiranoglu, M. and Twardella, D. (2008) Chemical and morphological properties of particulate matter (PM₁₀, PM_{2.5}) in school classrooms and outdoor air, *Atmos. Environ.*, **42**: 6597-6605.
- Grahame, T. J. and Schlesinger, R. B. (2010) Cardiovascular health and particulate vehicular emissions: a critical evaluation of the evidence, *Air Qual Atmos Health*, **3**:3-27.
- Gupta, A.K., Karar, K. and Srivastava, A. (2007) Chemical mass balance source apportionment of PM₁₀ and TSP in residential and industrial sites of an urban region of Kolkata, India, *J. Hazard. Mater.*, **142**: 279–287.
- Hays, S.M., Gobbell, R.V. and Gamick, N.R. (1995) *Indoor Air Quality*, Solution and Strategies. New York, McGraw-Hill Inc.
- John, K., Karnae, S., Crist, K., Kim, M. Kulkarni, A. (2007) Analysis of trace elements and ions in ambient fine particulate matter at three elementary schools in Ohio. *J. Air Waste Manag. Assoc.* **57**: 394-406.
- Kornartit, C., Sokhi, R. S., Burton, M. A. and Ravindra, K. (2010) Activity pattern and personal exposure to nitrogen dioxide in indoor and outdoor microenvironments, *Environ. Int.*, **36**: 36-45.
- Lee, S. C., Li, W. and Ao, C. H. (2002) Investigation of indoor air quality at residential homes in Hong Kong-case study, *Atmos. Environ.*, **3**: 225-237.
- Levy, J.I., Dumyahn, T. and Spengler, J.D. (2002) Particulate matter and polycyclic aromatic hydrocarbon concentrations in indoor and outdoor microenvironments in Boston, Massachusetts, *J. Expo. Anal. Environ. Epidemiol.*, **12**: 104-114.
- Molnár, P., Bellander, T., Sällsten, G. and Boman, J. (2007) Indoor and outdoor concentrations of PM_{2.5} trace elements at homes, preschools and schools in Stockholm, Sweden, *J. Environ. Monit.*, **9**: 348-357.
- Molnár, P., Gustafson, P., Johannesson, S., Boman, J., Barregard, L. and Sällsten, G. (2005) Domestic wood

- burning and PM_{2.5} trace elements: personal exposures, indoor and outdoor levels, *Atmos. Environ.* **39**: 2643-2653.
- Montgomery, D. D. and Kalman, D. A.** (1989) Indoor/outdoor air quality: Reference concentrations in complaint free residences, *Appl. Ind Hyg.*, **4**: 17-20.
- Morawska, L., He, C., Hitchins, J., Gilbert, D. and Parappukkaran, S.** (2001) The relationship between indoor and outdoor airborne particles in the residential environment, *Atmos. Environ.*, **35**: 3463-3473.
- Nastov, J., Tan, R. and Dingle, P.** (2003) The use of Fibre Technology to control surface Dust and Bacteria contamination Environ, *Sci. Report Series*, **1**, Australia.
- Paschold, H., Li, W.W., Morales, H., Pingitore, N. E. and Maciejewska, B.** (2003) Elemental analysis of airborne particulate matter and cooling Water in west texas residences, *Atmos. Environ.*, **37**: 2681-2690.
- Peiyao S., Lixin W., Yang H. and Rui L.** (2015) PM_{2.5} Concentrations Indoors and Outdoors in Heavy Air Pollution Days in winter, *Procedia Engineering*, **121**: 1902-1906.
- Portaria n.º 353-A/2013 de 4 de Dezembro,** (2013) Requisitos de ventilação e qualidade do ar interior, Diário da República, 1ª série e N.º 235-4 de dezembro de 2013. Ministérios do Ambiente, Ordenamento do Território e Energia, da Saúde e da Solidariedade, Emprego e Segurança Social.
- Ramachandran, G., et al.** (2000) Comparison of short-term variations (15-minute averages) in outdoor and indoor PM_{2.5} concentrations, *J. Air Waste Manag. Assoc.* **50**: 1157-1166.
- Reisen, F., Meyer, C.P. and Keywood, M.D.** (2013) Impact of biomass burning sources on seasonal air quality, *Atmos. Environ.* **67**: 437-447.
- Reto, M., Christian, S., Marloes, E., Inmaculada, A., Regina, E. D., Alex, I., Mark, D., Harish, C. P., Nicole, P., Ming-Yi, T. and Nino, K.** (2015) Modeling indoor air pollution of outdoor origin in homes of SAPALDIA subjects in Switzerland, *Environment International*, **82**: 85-91.
- Schneider, T., Sundell, J., Bischof, W., Bohgard, M., Cherrie, J. W., Clausen, P.A., Dreborg, S., Kildeso, J., Kjaergaard, S. K., Lovik, M., Pasanen, P. and Skyberg, K.** (2003) 'EUROPART' Airborne particles in the indoor environment, A European interdisciplinary review of scientific evidence on associations between exposure to particles in buildings and health effects, *Indoor Air*, **13**: 38-48.
- Srivastava, A. and Jain, V.K.** (2003) Relationships between Indoor and Outdoor Air Quality in Delhi, *Indoor and Built Environ.*, **12**: 19-165.
- Stranger, M., Potgieter-Vermaak, S.S. and Van Grieken, R.** (2007) Comparative overview of indoor air quality in Antwerp, Belgium. *Environ. Int.*, **33**: 789-797.
- Stranger, M., Potgieter-Vermaak, S.S. and Van Grieken, R.** (2008) Characterization of indoor air quality in primary schools in Antwerp, Belgium. *Indoor Air*, **18**: 454-463.
- Stranger, M., Potgieter-Vermaak, S.S. and VanGrieken, R.** (2007) Comparative overview of indoor air quality in Antwerp, Belgium, *Environ. Int.*, **33**: 789-797.
- Turiel, I.** (1985) *Indoor Air Quality and Human Health*, Stanford, CA, Stanford University Press.
- U. S. Environmental Protection Agency (EPA)** (1996) *Indoor Air Quality Office of Radiation and Indoor Air*, Indoor Environments Division (6607 J) EPA – 402- F-96-004.
- Yip, F. Y., Keeler, G. J., Dvonch, J. T., Robins, T. G., Parker, E. A., Israel, B. A. and Brakefield-Caldwell, W.** (2004) Personal exposures to particulate matter among children with asthma in Detroit, *Michigan. Atmos. Environ.*, **38**: 5227-5236.

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 (PM_{10} و $PM_{2.5}$) في الهواء الداخلي والخارجي من منازل مختلفة تستخدم وسائل التدفئة، تقع في مدينة سكاكا شمال المملكة، خلال موسم الشتاء. التركيب العنصري لعينات PM_{10} و $PM_{2.5}$ ، بما في ذلك، Al, Ba, Be, Ca, Cd, Co, Cr, Fe, Ga, K, Li, Mg, Mn, Na, Ni, Pb, Se, Te and Ti Inductively Coupled Plasma-mass Spectroscopy). وقد تم قياس الكربون الأسود (BC) أيضاً باستخدام EEL-type Smoke Stain Reflectometer. وأظهرت النتائج أن أعلى تركيز داخلي (٥٤١,٦٧ ميكروجرام للمتر المكعب) لـ $PM_{2.5}$ و (١٢٠١,٣٩ ميكروجرام للمتر المكعب) لـ PM_{10} تم رصده في المنازل التي تستخدم الخشب في التدفئة. أظهرت تركيزات المعادن النادرة لـ PM_{10} و $PM_{2.5}$ في الهواء الداخلي أن الصوديوم والحديد والألومنيوم كان الأعلى تركيزاً، لوحظ أن أعلى تركيز للكربون الأسود وجد في المنازل التي تستخدم الخشب للتدفئة. في المنازل المتشابهة في وسائل التدفئة، وجد أن زيادة عدد الأشخاص المدخنين أدى إلى ارتفاع قيمة الكربون الأسود.