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Levels and indoor–outdoor relationships of PM_{10} and soluble inorganic ions in Beirut, Lebanon

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ABSTRACT

PM_{10}, which is considered among the major indoor and outdoor pollutants, was measured in several residential homes and corresponding outdoor environments in the Great Beirut area over the summer and winter seasons of 2005. Few studies on PM_{10} levels indoors in Beirut are restricted to short-term periods in public places. In this study, 78 PM_{10} samples were collected on Teflon filters using an active sampler at a flow rate of 5 L/min. PM_{10} mass concentrations were determined by gravimetric analysis, and inorganic chemical speciation was carried out using ion chromatography. Outdoors, PM_{10} elevated mass concentrations correlated well with high traffic density. The observed high intra-site temporal variation (minimum of 34 and a maximum of 120 $\mu g/m^3$) was attributed to the dynamic air masses passing over the Eastern Mediterranean region. Indoors, PM_{10} levels were highly affected by outdoor levels, but were enhanced over those of outdoors when smoking activities were recorded. In winter, the overall average outdoor concentration dropped by 19%, whereas the average indoor concentration increased by 50% over the ones calculated for the summer. Ventilation and air exchange rates were found to be approximately equal to unity during summer since most doors and windows remain open. This rate drops to almost half during winter. As for particulate ions namely nitrates and sulfates, the former showed concentrations that are higher than the values reported in the region in both winter and summer seasons, suggesting high emissions from local vehicles. However, SO_4^{2-} average concentrations were comparable to values reported in other studies conducted in Eastern Mediterranean sites. Soluble particulate nitrates and sulfates exhibited similar indoor and outdoor levels in non-smoking homes (IO~1), but in smoking homes the drop in nitrate concentrations reached around 70%, indicating a high anionic reactivity with tobacco smokes.

1. Introduction

Interest in indoor air chemistry and variations of airborne particles between indoor and outdoor atmospheres is mainly fueled by the fact that humans spend most of their time indoors. The number of hours people spend indoors can vary with gender, occupation, age and status. Still, on average people tend to spend between 85 and 90% of their time exposed to the indoor rather than the outdoor atmosphere (Schweizer et al., 2007; Chang et al., 2003).

The major outdoor anthropogenic pollutants have been well characterized: primary particulate matter (PM) is generated from direct combustion sources and dust suspension while secondary PM is formed form gas precursors by a gas-to-particle conversion (GPC) process (Moreno et al., 2004). Secondary sulfates and nitrates, which are dominant constituents in PM for suburban and rural sites (Zhao and Hopke, 2006) result from such ionic conversions. Their concentrations in PMs are functions of insolation and evaporation and consequently are season dependent.

In the absence of indoor sources, the indoor environment is very much dependent on the outdoor environment with a more effective penetration of fine particles than coarse

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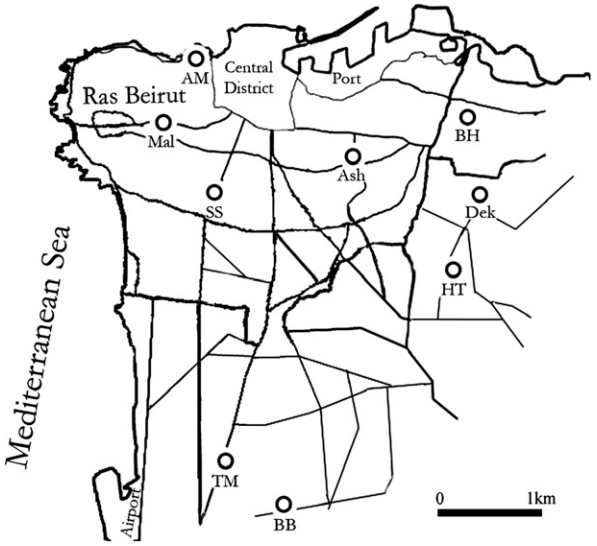

Fig. 1. Locations of the different sampling sites in Beirut.

particles from outdoors into the house (Liao et al., 2004). In these cases the ratio of indoor to outdoor PM levels was reported between 0.5 and 0.7 (Monn et al., 1997; Wallace, 1996) where differences between outdoor and indoor air quality are attributed to rates of deposition and infiltration. However, in the presence of internal sources/human activities like smoking, cooking, cleaning, resuspension due to perturbations, indoor soil and combustion activities, indoor PM levels become significantly affected and can consequently grow to be much higher than levels outdoors (Jones et al., 2000; Wallace, 1996; Zhao and Hopke, 2006).

Many studies attempting to measure the indoor to outdoor ratio (IO) relied on previously established or common outdoor levels as a denominator for indoor measurements. However, when dealing with PM_{10}, it is of high importance that simultaneous or consecutive measurements be taken between indoor and outdoor environments since the deposition velocity of coarse particles is higher due to gravitational settling (Liao et al., 2004) and therefore temporal variations prove to be greater for coarse size mode particles than for fine particles.

The work presents the first study on human exposure to PM indoors in Beirut. The city of Beirut experiences elevated outdoor PM levels and indoor air quality is almost inexistent. The objectives of the present study are to characterize the PM_{10} levels at various residences in Beirut and to examine the relationship between the indoor and outdoor concentrations by measuring consecutive outdoor and indoor PM_{10} and ion concentrations in various sites in Beirut. Results of the ionic chemical analysis of the collected filters allows to identify specific tracers once they infiltrate to indoor environments. The analysis of our results would permit further characterization of air quality and better evaluation of the direct risk resulting from air pollution on the human health.

2. Experimental procedure

2.1. Location of the sampling sites

Seventy-eight PM_{10} samples were collected in different residential places, located in Beirut and its suburbs known as Great Beirut. Sites indicated on the map (Fig. 1) are: Ain el-mreiseh (*AM*), Ashrafieh (*Ash*), Borj El-Barajneh (*BB*), Borj Hammoud (*BH*), Dekweneh (*Dek*), Horsh Tabet (*HT*), Mallah (*Mal*), Salim Slem (*SS*), and Tarik El-Matar (*TM*). PM_{10} were sampled in nine separate homes in summer between June and October 2004 (*AM*, *Ash*, *BB*, *BH*, *Dek*, *HT*, *Mal*, *SS*, and *TM*). A similar procedure was adopted for six residential sites during winter between January and March 2005 (*Ash*, *BB*, *HT*, *Mal*, *SS*, and *TM*). At each home, three indoor and three outdoor PM_{10} measurements were taken in summer and two indoor and two outdoor measurements in winter. Indoor and outdoor PM_{10} concentrations were measured alternatively on two consecutive days having to an extent similar weather and pollution conditions in order to validate the indoor–outdoor comparison. Indoor measurements were taken in the living room while outdoor samples were collected at the closest balcony to the living room of the same sampled house. While all residents relied on gas stoves for cooking, the sites had different number of occupants, heating and cooling systems, smoking habits and were located in areas with various traffic densities (Table 1).

2.2. Sampling methods and analysis

Each PM_{10} measurement was conducted using the Mini-Partisol Air Sampler model 2100 (Rupprecht and Patashnick Co.). It consisted of a top-mounted bracket containing a particle inlet for PM_{10} and a single 47 mm filter holder, which was used for PM sampling. Each PM_{10} sample was collected on a PTFE Teflon filter for a 24-hour period at a sampling rate of 5 L/min. The Teflon filters used for PM_{10} collection were

Table 1
Detailed description of the nine residential sites sampled in summer

Location	Floor	Busy road	No of occupants	Smoking cigarettes/day	Narghile sessions	Heater	Ventilation
AM	1	No	1	20–25	No	Electrical	Natural
Ash	1	No	2	No	No	Electrical	Natural
BB	4	Yes	6	1–3	No	Gas	Natural
BH	2	Yes	4	20–23	No	Electrical	Natural
Dek	3	Yes	3	10–15	Rarely	Electrical	Occasional usage of Air conditioning
HT	6	No	5	Rarely	No	Electrical	Extensive usage of Air conditioning
Mal	4	Yes	7	40	5–13	Charcoal	Natural
SS	4	Yes	4	15–27	No	Electrical	Natural
TM	1	Yes	4	28–59	No	Electrical	Natural