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Real-time indoor and outdoor measurements of black carbon at primary schools

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HIGHLIGHTS

- Indoor and outdoor Equivalent Black Carbon (EBC) measured at 39 primary schools.
- Indoor exposures greatly determined by outdoor concentrations.
- Strong dependency of indoor and outdoor EBC levels on the distance to traffic.
- Mean EBC at different districts related with the surface area used for road network.
- Indoor/outdoor ratios >1 at nights maybe linked to the airtightness of the classroom.

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ABSTRACT

Epidemiological and toxicological studies have demonstrated the association between Black Carbon in indoor and outdoor air and the occurrence of health risks. Data on air quality in schools is of special interest, as children are more vulnerable to health hazards. In this context, indoor and outdoor measurements of real-time Equivalent Black Carbon (EBC) were collected at 39 primary schools located in Barcelona (Spain), with classrooms naturally ventilated under warm weather conditions. A main contribution of road traffic emissions to indoor and outdoor EBC levels was evidenced through different approaches. Simultaneous measurements of EBC levels at schools under different traffic conditions revealed concentrations by 30–35% higher at schools exposed to higher vehicles intensities. Moreover, a significant correlation was obtained between average outdoor EBC levels at different districts of the city and the percentage of surface area in each district used for the road network ($R^2 = 0.61$). Higher indoor than outdoor levels were recorded at some instances when the indoor sampling location was relatively closer to road traffic, even under low outdoor temperatures. Indeed, the average indoor/outdoor EBC ratios for each school correlate moderately between campaigns in spite of significant differences in temperature between sampling periods. These two facts highlight the strong dependency of the EBC levels on the distance to traffic. The peaks of exposure inside the classrooms seemed to be determined by outdoor concentrations, as shown by the parallelism between indoor and outdoor mean EBC daily cycles and the similar contribution of traffic rush hours to indoor and outdoor daily mean levels. The airtightness of the classroom was suggested as the responsible for the indoor/outdoor ratios of EBC higher than 1 recorded at nights.

1. Introduction

Carbonaceous material normally accounts for 10–50% of the ambient air particulate matter (PM) mass concentration (Putaud

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et al., 2010). Equivalent Black Carbon (EBC) is an operationally defined term which describes carbon as measured by light absorption (Petzold et al., 2013). As such, it is not the same as elemental carbon (EC), which is usually monitored with thermal-optical methods, although both terms are sometimes used as equivalent. Current measurement methods for EBC and EC need to be standardized so as to facilitate comparison between the results of various studies (Baumgardner et al., 2012; Querol et al., 2013). In general, EC or EBC are considered as having negligible toxic effects on human and animal lungs in controlled studies and on airway cells such as macrophages and respiratory epithelial cells. Instead, it has been suggested that they exert an indirect key role in toxicity as a universal carrier of toxic semi-volatile organics and other compounds co-released in combustion processes or attached to their surface during regional and long-range transport (WHO, 2012). Time-series study design has been the most frequently used method to evaluate the acute effects of EBC exposure on population health. Epidemiological studies provide sufficient evidence of the association of cardiopulmonary morbidity and mortality with EBC exposure (Janssen et al., 2005; Suglia et al., 2008; Power et al., 2011). Janssen et al. (2011) concluded that the effect of a 1 $\mu g\ m^{-3}$ increase in EBC on all-cause mortality is at least eight times larger than the estimated effect of a 1 $\mu g\ m^{-3}$ increase in PM_{10}. Indeed, the recent WHO report concluded that “reduction in exposure to $PM_{2.5}$ containing EBC and other combustion-related PM material for which EBC is an indirect indicator should lead to a reduction in the health effects associated with PM” (WHO, 2012).

There are several biological reasons why young children may be more susceptible to air pollution's effects. Compared to adults, children have a larger lung surface area in relation to their body weight, and breathe 50% more air per kilogram of body weight (Moya et al., 2004). The process of early growth and development is important for the health of the child, and therefore may also be a critical time when air pollution exposures can have lasting effects on future health. Thus, many epidemiological studies have assessed the relation between EBC and health hazards among children cohorts. In Suglia et al. (2008) authors demonstrated that higher levels of EBC predicted decreased cognitive function across assessments of verbal and nonverbal intelligence and memory constructs in children. According to Jung et al. (2012), childhood exposure to EBC may contribute to the development of wheeze symptoms among children ages 5–7 years. Chiu et al. (2013) reported the link between exposure to EBC and attention difficulties in low-income urban children and found differences between the genders. Findings in Kim et al. (2004) supported the hypothesis that traffic-related pollution is associated with respiratory symptoms in children. Kim et al. (2013) described a significant increase in the risks based on the odds ratios of treatment experiences for allergy-related diseases such as asthma and allergic rhinitis in the school group with traffic-related pollutants in comparison to the school groups with no exposure to pollutants. Spira-Cohen et al. (2011) reported that the diesel soot fraction of $PM_{2.5}$ is a key responsible for pollution-related asthma exacerbations among children living near roadways.

When interpreting effect estimates for EBC in epidemiological studies, information on the main sources in the area of study should be considered. Vehicular traffic, especially diesel-powered, is a major source of EBC in urban areas (Pakkanen et al., 2000; Rodríguez and Cuevas, 2007; Reche et al., 2011; Vanderstraeten et al., 2011; Querol et al., 2013). In fact, a number of authors suggest that a more suitable traffic-related policy measure should be stated in terms of EBC concentration reduction (Janssen et al., 2011; Vanderstraeten et al., 2011; Invernizzi et al., 2011; Anenberg et al., 2012). However, in some areas, residential burning of wood or coal, and at least periodically open biomass burning (Sandradewi et al., 2008), may be even more important sources of EBC. More locally, harbors and industrial facilities may have a pronounced effect on EBC concentrations. The spatial variation of EBC is much larger than that of PM mass at the city-scale (Hoek et al., 2002; Wang et al., 2011), this being mainly related with the contribution of road traffic.

In recent years, the need to collect more information on infiltration of outdoor traffic-related particles in relevant indoor environments has been recognized as an important research topic (Jamriska et al., 2000; Eisner et al., 2009; Viana et al., 2011; El-Batrawy, 2011; Stabile et al., 2012). The infiltration factor is defined as the equilibrium fraction of ambient particles that penetrate indoors and remain suspended (Long et al., 2001). According to literature, outdoor EBC has been found to be more strongly associated with respective indoor levels than PM mass in cross-sectional studies (Gotschi et al., 2002; Van Roosbroeck et al., 2008). Source apportionment studies of indoor EBC sources are relatively scarce, with major contributions being typically related with outdoor sources. In Viana et al. (2011), printing and photocopying was estimated to contribute with 25–30% of total indoor EBC in offices, with the rest being attributed to infiltration of traffic emissions. La Rosa et al. (2002) identified cooking and candle burning as the main indoor sources of EBC in an occupied house, contributing 16 and 31%, respectively, of the annual average indoor concentrations. Lanki et al. (2007) and Raaschou-Nielsen et al. (2010) highlighted that EBC indoor sources, such as cooking and environmental tobacco, may lead to peaks in exposure.

Assessing school-based exposures to EBC is needed for characterizing and preventing children's health risks to air pollutants, as one of the more vulnerable sectors of the population. Buonanno et al. (2013) identified transportation as the main activity contributing to the overall daily exposure of children to EBC. Raysoni et al. (2013) examined children's exposure to traffic-related air pollutants at four elementary schools in Texas (USA), and concluded that indoor air pollution was generally well-correlated with outdoor air pollution. Hochstetler et al. (2011) characterized the indoor and outdoor EC levels at four urban elementary schools serviced by diesel-powered school buses, and determined that outdoor mass concentrations were highest at the school with the greatest number of buses. Some studies suggested that cessation of school bus idling will produce improved local EBC concentration outside schools (Richmond-Bryant et al., 2011; Ryan et al., 2013). In a study in schools and pre-schools in Stockholm (Sweden), Wichmann et al. (2010) reported that indoor environments offer little protection against combustion-related particles in the outdoor air, and authors do not detected significant indoor-generated soot.

The present work aims to characterize levels, sources and indoor–outdoor relationships of EBC in Barcelona schools (Spain). The ultimate objective is to assess children indoor and outdoor exposure to traffic-related EBC at schools of Barcelona (Spain) as part of the ERC Advanced Grant BREATHE (http://www.creal.cat/projectebreathe). In this context, differences in indoor and outdoor exposure to EBC as a function of the schools' environments (urban background vs. traffic-oriented) are also discussed.

2. Methodology

Measurements within this work were collected in the framework of the BREATHE project (http://www.creal.cat/projectebreathe). An extensive description of the study area and the methodology employed for the characterization of air pollutants can be found in Rivas et al. (2014).

The study was performed in the city of Barcelona (15.583 inhabitants km^{-2}) and in the neighboring municipality of Sant Cugat del Vallès (1760 inhabitants km^{-2}; IDESCAT, 2014). Both