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Air quality in tramway and high-level service buses: A mixed experimental/modeling approach to estimating users' exposure

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ABSTRACT

Airborne particulate matter (PM) and particle-bound polycyclic aromatic hydrocarbons (PAHp) were monitored both inside and outside of a tramway and two types of high-level service buses within a major French conurbation. The air quality variations among tramway and the different bus rapid transit systems were large and significant. This proved to be a complex issue involving contamination and clearance processes, as evidenced by mechanisms like in-vehicle PM generation and indoor accumulation of the outdoor PAHp pollution. Given these empirical results, a simple lung-accumulation model has been formulated in order to estimate the public transport users' (PTU) exposure during their journey. Calculations draw attention to situations and categories of individuals to be targeted by clean air policies. For instance, despite being chronically exposed to excessive concentrations in heavily built-up and trafficked areas, PTU would accumulate in their lungs 4–11 times less PM and PAHp than nearby pedestrians walking the same route. These pedestrians are more likely to experience short episodes of strong lung accumulations. Moreover, the numerical approach employed herein allowed: (i) estimating a distance at which walking could be considered a viable alternative to the use of public transport services; (ii) probing the relevance (in terms of lung accumulations) of both EU and US standards; and (iii) proposing exposure reduction strategies.

1. Introduction

Initiatives have been undertaken in many urban areas around the world in an effort to promote the modal shift away from the private automobile and towards public transportation, with the aim of reducing pollutant emissions. This is through the lowering of the number of vehicles in circulation, thus yielding less congestion and fewer emissions (Joumard et al., 1996; Almasri et al., 2011; Batty et al., 2015; Schindler and Caruso, 2014). Among these initiatives, public transport with specific rights-of-ways, also referred to as dedicated public transport services, offers the dual advantage of streamlining vehicle movements within the overall urban flow and reducing fuel consumption and related pollutant emissions through improved vehicle operating regularity (Gonçalves et al., 2009; FTA, 2016). Moreover, such a policy often comes with the deployment of electrically-powered public transport vehicles (PTV). To date however, very little information is available on the air quality at the scale of public transport users (hereafter referred to as PTU) and their surrounding atmosphere.

Involved for several years in crafting a transport policy intended to favor the shift from the private automobile to public transport, the City of Nantes (France) and its metropolitan council (Nantes-Métropole, 600,000 inhabitants) has implemented a variety of rapid public transport systems on various urban arterials (EC, 2016). This policy move has provided an opportunity to assess the quality of

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air being breathed by PTU, both inside and outside of the various types of vehicles from dedicated public transport services. Nantes' dedicated public transport services consist of the tramway (TW) and two types of high level-of-service bus lines, i.e.: the so-called “chronobus” (CB) and “busway” (BW) (see Section 2.3 for more details). As part of the city's strategy to reduce the airborne particulate matter (PM) and polycyclic aromatic hydrocarbons (PAH) exhaust emissions along with their respective increased risks with respect to cardiovascular and respiratory diseases or cancer (Gros et al., 2007; Lim et al., 2012; Silva and Mendes, 2012; Vuković et al., 2014; Abdel-Shafy and Mansour, 2016; Chart-asa and Gibson, 2015; Kiesewetter et al., 2015; Ghosh et al., 2016), CB and BW are both powered by natural gas, while the tramway runs on electricity.

This study tests the hypothesis that implementation of high level-of-service transportation modes takes part in the improvement of air quality inhaled by individuals in the different phases of their travels. These targeted phases relate either individuals in PTV (hereafter designated as passengers) or waiting at stations. The current study also targeted individuals walking in the vicinity of transit lines (e.g. to reach or depart from stations; hereafter designated as pedestrians). Air quality is assessed through particulate matter (PM) and particle-bound PAH (hereafter referred to as PAHp) concentrations. To fully explore this hypothesis, mobile measurements are carried out inside PTV (as previously conducted for private automobiles by Chan and Chung, 2003; Tartakovsky et al., 2013), at different stations where they stop and alongside public transport lines. More specifically, the three main objectives of this research are:

(i) to identify the greatest possible range of causes of variation in the air quality inhaled by PTU or pedestrians walking alongside the rapid public transport lines;
(ii) to estimate lung-particulate accumulations for PTU and pedestrians walking the same route, in order to propose readily achievable exposure reduction strategies;
(iii) to examine the relevance of air quality standards in terms of particulate-pollutant exposures to PTU and pedestrians.

Many factors likely influence the air quality in PTV and the particulate pollution exposure to PTU. These include, but are not limited to: travel time, spatial and temporal variations in the air pollution, cabin filtration systems, if any, and, micrometeorological factors that might direct pollutants into the cabin. However, only a limited amount of study tackles the important task of evaluating both the in-vehicle particle generation mechanisms (Behrentz et al., 2004) and the interactions between outdoor particulate pollution and in-vehicle air with a focus on high level-of-service transportation modes (Moreno et al., 2015).

The study area characteristics, data collection protocol, analytical devices and model implemented to estimate PTU exposure will all be presented first. Next, the results of air quality along public transport lines, at stations, inside PTV, along with estimates of particulate accumulation in the lungs among the various situations will be presented. Finally, results will be discussed with respect to local sources, contamination and clearance processes, practicable exposure reduction strategies and the set of relevant EU and US regulations.

2. Materials and methods

2.1. Study area

The dedicated public transport services under examination lie at the heart of the Nantes (France) public transportation network, covering an island 4.9 km long by 1 km wide (area of 3.4 km^2) bordered by the Loire River (47°12′17″ N, 1°32′46″ W) (Fig. 1). This small island features consistent weather conditions and vehicle fleet composition, which created a good opportunity to produce a reliable comparison of the air quality provided to PTU under relatively homogeneous urban background conditions (Choi et al., 2013; Font et al., 2014; Oxley et al., 2015). According to the Nantes Metropolitan Council (2012), this island constitutes a transit zone in concentrating the north-south car traffic flows (i.e. with close to 100,000 trips a day). Air quality was assessed inside vehicles, at stations and in the immediate vicinity of public transport lines.

2.2. In situ measurements

Four air quality measurement campaigns were held during the spring-summer of 2014. The overall weather conditions encountered over the course of each campaign are indicated in Table 1. Both the particle size distribution and PAHp concentration were measured using an autonomous device (see the analytical section). The device was securely seated into cushioning foam and placed in a 2-wheel shopping trolley, which was manually maneuvered on city streets or, similar to Moreno et al. (2015), placed on the central PTV platform (> 0.5 m from the walls). With the exception of the second campaign, most of the PTV windows were kept closed while passengers preferentially sat near the central platform or exit doors. Pollutant exchanges between the in-vehicle air and the environment were estimated using a two-component mixing equation:

$$V_{PTV}C_{PTVf} = (V_{PTV}-V_{EX})C_{PTVi} + V_{EX}C_{ENV} \quad (1)$$

where V_{PTV} and V_{EX} denote respectively the in-vehicle and exchanged air volumes, while C_{ENV}, C_{PTVi} and C_{PTVf} stand for concentrations in the environment and inside the vehicle before and after exchanges take place. The number of passengers did not markedly changed between two successive segments, hence had little influence and we compared the pollution level variability in PTV to this of crossed areas (Appendix A). To do this, in-vehicle variations of particulate and PAHp concentrations were recorded during PTV operations. This allowed identifying situations of marked in-vehicle contamination with outdoor PAH-loaded particles