CAR COMMUTERS’ PERSONAL EXPOSURE TO ULTRAFINE PARTICLES

Extended abstract

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Background

Ultrafine particles (UFPs, diameter < 100 nm) exposure has been associated to both short and long term health effects, however the specific or enhanced toxicity of UFPs with respect to other particle fractions has not been established yet. UFPs can be generated by indoor sources or can affect indoor environments due to infiltrations of particles outdoor generated. The main sources of UFPs are combustion related emissions, mainly, in urban settings, those from vehicles. People spent a minority, largely variable, though significant part of their time inside passenger cars. Recent studies (carried out in the US, Australia, central and north Europe) show that in-car exposure could significantly contribute to total integrated exposure estimates (Knibbs et al., 2011). In-car exposure studies in the Mediterranean basin area are scarce (e.g. Tartakovsky et al., 2013). To date, only one study assessing inside cars exposure within an Italian large urban settings is available (Cattaneo et al., 2009).

Rome, the Italian largest and most populated municipality with 2,724,347 residents in 1,285.3 km², is characterised by alternate zones of very high urbanisation and population density and zones where urbanization is lower or absent.

The main sources of particles originate from road traffic combustion. Traffic flow is rather high during work days with two rush hours (morning and late afternoon). Traffic flow easily exceed 20,000 vehicles per day in the main streets. Since 2001 particles number concentration (PNC), the parameter most used to estimate UFPs exposure, has been continuously measured in Rome, starting from the framework of the HEAPPS study (Aalto et al., 2005). A previous study shows a statistically significant decreasing trend for primary gaseous pollutants and PNC measured in Rome, mainly due to the progressive shifts towards vehicles meeting the most stringent European emissions standard, which was enhanced by national and local measures (Cattani et al., 2010).

To overcome some limitations of long term UFPs exposure studies, based on one or few outdoor measuring sites, data on indoor exposure to UFPs as well as their outdoor spatial variability, still lacking in Italy, are needed. Within the framework of the ongoing VIAS project, aimed to assess the air pollution impact on health, this pilot study aims to assess for the first time in Rome, real-world UFPs personal exposure during systematic travel home to work of mid aged, roman office building employees as well as to estimate the contribution of in car exposure to the total integrated exposure.

Methods

To measure PNC four hand-held, real time condensation particle counters (CPC) were used (model 3007, TSI, MN, USA; minimum detectable particles size 10 nm). Measurements time resolution was 1s.

Two routes were selected for this study, with different origin and same destination. The first (R1) was 12,6 km long, from the city centre to the city south, through an high traffic urban street (three carriageway). The second (R2), 21,3 km long, has origin in the suburban periphery and gets the same destination throughout the Great Ring Junction (GRA), a dual-carriageway, three-lane, toll-free highway. Two vehicle ventilation modes were studied:

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- air conditioning (AC) and ventilation fan switched off and driver’s window partially opened (WIN MODE);
- AC switched on, windows closed and cabin air internal recirculation switched on (REC MODE).

All experiments were carried out during working days.

Aimed to compare the in-car PNC with other indoor environments, PNC measurements have been undertaken in 3 private homes and one office building (during typical 8 hours working days). The investigated microenvironments were the kitchen (during cooking and while eating breakfast or dinner), the living room and the bedroom (during night). Measurements have been carried out following one selected inhabitants daily activities as the in-car experiments.

All the people involved in this study were non smokers. Moreover measurements have been carried out in 31 outdoor sites, to estimate spatial variability of outdoor PNC. Each site measurement lasts one week. Each day, three sampling periods have been selected, lasting two hours each, to estimate a daily average.

All the data collected were used to build a reliable integrated UFPs total exposure estimate. Descriptive statistics have been calculated starting from 1min averages of the 1s riding data set. The statistical analysis of collected data was performed by means of the R software (R Development Core Team, 2011).

Results and discussion

28 runs were performed during late spring/summer 2013. Average time spent in car during R1 was 40 min (±8 min) while average R2 lasted 28 min (±7 min) excluding an exceptionally long trip due to high traffic (115 min). About half of the R2 time (13 min ± 6 min) was spent in the GRA highway. The average R1 speed was 18.9 km h⁻¹, while the average R2 speed was 45.6 km h⁻¹.

Fig. 1. Box plot of PNC (1 min averages) measured in several microenvironments: R1 WIN MODE (A); R2 WIN MODE (B); R1 AC MODE (C); R2 AC MODE (D); kitchen during cooking (E); living room (F); bedroom, night (G); office building (H); outdoor all measurements in 31 sites (I).

The PNC highest median was found during R2 trip in WIN MODE (46,293 particles cm⁻³); R1 trip PNC median in WIN MODE was 33,520 particles cm⁻³. Both data sets showed remarkable variability. Interquantile range was respectively 52,727 particles cm⁻³ and 30,768 particles cm⁻³. The differences found are likely due to differences in traffic parameters between different routes. The R1 trip is characterised by lower average speed due to a number of traffic lights during the route; some tract was also often very busy. About half (13 min) of the R2 average time is spent on the GRA freeway, characterised by higher speed allowable, no traffic light, higher traffic volume and different vehicles composition with higher heavy diesel traffic volume. PNC median calculated over the R2 GRA section ranging between 47,994 and 87,471 particles cm⁻³, in the WIN MODE.

In vehicles PNC can be efficiently reduced using the AC with recirculation (see Fig 1, box plot C and D, REC MODE). Also variability was reduced; the differences between the two routes were still evident. Personal commuters habits play a major role determining in-car exposure; particularly using AC (with or without recirculation) or keeping the car windows open. The last option is often the primary choice during the warm season in Rome, lasting from April to October, due to prevailing warm temperature during the morning day. Extensive use of AC is limited to the warmer months (i.e. July and August). These conditions are very different from those typical in central-north Europe, where the main studies available have been carried out. Using AC with recirculation raises the issue of CO₂ accumulation inside the vehicle’s cabin: previous findings show that in a 30 min trip CO₂ concentration can easily increase over 2,000 ppm (e.g. Tartakoswky et al., 2013).

Both indoor and outdoor PNC measured in several other microenvironments were found to be much lower than those found in car cabins. The only exception was PNC median measured indoor in the kitchen during cooking.
(32,296 particles cm\(^{-3}\)). Note that the kitchen data set include time spent during cooking and time spent after cooking during eating and cleaning activity. We observe that the mean time needed to PNC fall down to background indoor concentrations was 30 min.

Fig. 2. Pattern of PNC during a traffic congestion event; R2 route.

Fig. 2 illustrate the short term traffic pattern during a traffic congestion event (measurements time resolution 1s). The highest spikes have been observed when the car was driven behind a heavy duty vehicle or older diesel cars. In car PNC decreased rapidly after switching from WIN MODE to REC MODE. Crossing the tunnel at reduced speed allows the PNC to rise up to 150,000; PNC was higher then 100,000 particles cm\(^{-3}\) until the tunnel exit. Mean PNC within the GRA tract of the trip was about 8 times the contemporary mean outdoor background PNC. Traffic congestion events though if occurs in a minority of days during the year, are quit frequent particularly during morning and late afternoon rush hours.

To estimate personal exposure to UFP we used the available micro-environmental concentrations and the time spent in these microenvironments from literature time–microenvironment–activity patterns (see Table 1).

The estimate was related to mid aged (30 – 65 years old), office building employees, that travel systematically home-to-work by car within the Rome municipality borders. Average time spent daily driving in Rome was estimated 74 min; this Fig. accounts for about half of systematic home-to-work travels (ANCI 2009); median total time spent indoor at home for Italian people was estimated by Schweizer et al. as 13.1 hours per day (ranging between 8.1 h d\(^{-1}\) – 22.5 h d\(^{-1}\)) and time spent indoor at office as 7.50 h d\(^{-1}\) (0.3 h d\(^{-1}\) – 12.3 h d\(^{-1}\)) (Schweizer et al., 2007).

Table 1. Estimated relative contributions of each considered microenvironment to UFPs exposure based on R1 route experiments

<table>
<thead>
<tr>
<th>Microenvironment</th>
<th>Median time spent (h d(^{-1}); %)</th>
<th>Median PNC (particles cm(^{-3}))</th>
<th>PNC exposure (particles cm(^{-3}) h)</th>
<th>Relative contribution to total integrated exposure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-car WIN MODE</td>
<td>1.1 (4.6%)</td>
<td>33,520</td>
<td>36,872</td>
<td>12.4%</td>
</tr>
<tr>
<td>Outdoor</td>
<td>2.3 (9.6%)</td>
<td>11,876</td>
<td>27,315</td>
<td>9.2%</td>
</tr>
<tr>
<td>Home - bedroom</td>
<td>7.0 (29.2%)</td>
<td>6,602</td>
<td>46,214</td>
<td>15.5%</td>
</tr>
<tr>
<td>Home - kitchen</td>
<td>1.5 (6.3%)</td>
<td>32,296</td>
<td>48,444</td>
<td>16.3%</td>
</tr>
<tr>
<td>Home - living room</td>
<td>4.6 (19.2%)</td>
<td>14,039</td>
<td>64,579</td>
<td>21.7%</td>
</tr>
<tr>
<td>Office</td>
<td>7.5 (31.3%)</td>
<td>9,934</td>
<td>74,505</td>
<td>25.0%</td>
</tr>
</tbody>
</table>

In this scenario commuting by car relative contribution to total integrated exposure became as important as others microenvironments, where time spent was higher but average PNC was much lower (e.g. bedroom or office). The effective contribution was strictly dependent upon drivers’ habits and routes followed during travel. The R2 routes determine an higher contribute to total exposure (16.3%). Using AC plus recirculation allows for strongly reduce the in-car contribution to total exposure (1.8% for R1 route, 5.4% for R2 route).

Concluding remarks

Our study suggests that commuting by car significantly contributes to UFPs total integrated exposure. Short term high PNC and large variability characterised the in car cabin pattern of exposure. Drivers habits like driving with open windows is a key factor on determining exposure levels; driving with AC and cabin air recirculation completely changes the exposure pattern. Meteorological factor is the driving force for the commuter’s choice. To
improve the estimate, data collection during both warm and cold season, and a large scale survey on commuters’ habits are needed.

**Keywords:** indoor exposure, ultrafine particles, vehicle occupants exposure

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