Particle number concentration at urban microenvironments

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The number concentration levels of particles in the 20-1000 nm size range measured by means of a portable condensation particle counter at several indoor microenvironments and outdoor transport urban microenvironments in Milano are presented. Besides characterizing the various microenvironments in terms of particle number concentration, the experimental results allow the assessment of the individual exposure during everyday life activities and the daily exposure of commuters based on the typical time pattern of people commuting in Milan.

1. Introduction

Recent epidemiological and toxicological studies on particulate matter (PM) pollution focus on health effects associated with the exposure to fine particles, and present evidence of a closer correlation of PM related health hazards with number concentration rather than mass concentration (Donaldson et al., 2002; Peters et al. 1997; Wichmann et al. 2000). While particle mass concentration is dominated by larger particles, most of the number of particles is in the ultrafine size range (particle diameter $D_p < 100$ nm), and can reach and deposit in the alveoli region of the lung (Jaques and Kim 2000). Therefore, it has been suggested that particle number concentration could be used to better reflect the adverse health effect of the PM (Seaton et al., 1995).

Personal exposure to ultrafine particles (UFP) can occur both indoors and outdoors. Indoor UFP are a combination of ambient particles infiltrated into buildings and particles generated indoors during the daily activities of home occupants, like cooking, smoking or operating small electric appliances such as hair dryers, mixers, toasters.

It is widely recognized that, as people spend most of their time indoors, a significant portion of the personal exposure to particles occurs in indoor environments, where the exposure is often higher than the outdoor concentrations (Wallace and Ott, 2010); nonetheless, a significant contribution to daily total exposure can also derive from outdoor exposure in urban transport microenvironment, where people spend a substantial fraction of their outdoors time. The urban transport microenvironment includes different modes of surface (walking, cycling, car driving and public transport vehicles) and underground (subway) transportation, during which people are exposed to particle concentration levels which are often higher than anywhere else.

The concept of microenvironment (i.e. an indoor/outdoor area where the air pollutant concentration can be assumed homogeneous) has been created in order to help the atmospheric pollutant exposure assessment. The total exposure in a given time period is defined as the sum of the concentrations to which people are exposed in the microenvironments they visit, weighted by the fractional time spent in each microenvironment (Kruize et al., 2003).

The present work presents the number concentration levels of fine and UFP particles measured at different urban microenvironments. Measurements have been performed by means of a portable condensation particle counter at various indoor and transport microenvironments in Milano area (Italy). Indoor microenvironments include two houses (both kitchen and sitting room), an office, an office printing room, a public bar, a supermarket, a church during service, a hairdresser shop; transport microenvironments include pedestrian activities in urban areas, commuting trips by car, by train and by urban subway. Besides characterizing the various microenvironments in terms of particle number concentration, the experimental results allow the assessment of individual exposure during everyday life activities. In particular, based on the typical time-weighted scenario of people commuting in Milan, the daily exposition of commuters is estimated comparing different mobility options.

2. Materials And Methods

Particle number concentration was measured by means of a P-Trak Ultrafine Particle Counter (model 8525, TSI Inc., St. Paul, MN). This battery operated portable instrument utilizes the condensation particle counting technique to detect and count in real time (1-min time resolution) the particles in the range of 20 to 1000 nm. Particles, drawn through the instrument by a pump, pass first through a saturator tube where they mix with alcohol vapors, and consequently into a condenser tube which cools the air/particle stream causing alcohol to condense on the particles making them grow into detectable droplets. The droplets then pass through a focused laser beam, producing flashes of scattered light that are sensed by a photo detector and counted to determine particle number concentration (particles cm^{-3}). Despite a measurement concentration range up to $5 \cdot 10^5$ cm^{-3}, literature studies showed that for particle concentrations above 10^5 cm^{-3} coincidence errors will cause some under-reading in P-Trak data (Westerdahl et al., 2005). A lack in the detection of concentrations above $2 \cdot 10^5$ cm^{-3} was reported for P-Trak at outdoor urban microenvironments in Milano (Cattaneo et al., 2009). Moreover, caution must be given in interpreting P-Trak data collected near combustion sources since significant limitations in detecting freshly emitted ultrafine particles from vehicles, with a subsequent underestimation of the total particle number concentration, have been also reported (Zhu et al., 2006). In any case a good measurement performance is expected when sampling indoor ambient air.

Measurements at indoor microenvironments were performed simply keeping the instrument inside the room, without a particular direct exposition to potential particle sources; for outdoor measurements at transport microenvironments the instrument was placed in a backpack leaving out the sampling inlet.

3. Results And Discussion

3.1 Indoor microenvironments

The particle concentration levels measured in the kitchen (data number N = 500) displayed a large variability mainly related to different food processing operations and cooking activities; however, an average concentration level in the order of $3.9 \cdot 10^4$ cm^{-3} was recognized as the room background. The emissions associated to kitchen activities superimposed to this background level resulted in peak concentration levels up to $2 \cdot 10^5$ cm^{-3} during intense flame cooking and in the order of $1.7 \cdot 10^5$ cm^{-3} during flame frying. Cooking on gas or electric stoves and electric toaster ovens was recognized as a major source of UFP, with peak personal exposures often exceeding 10^5 particles per cm^3 (Wallace and Ott, 2010). An exponential decay of the particle concentration with a constant decay rate about 0.03 min^{-1} was observed in the kitchen room once cooking activity has finished: regardless of the absolute concentration values, the concentration level in the room was about 60% less than the peak after 30 minutes and about 80% less after an hour. A further, almost linear, decay in the concentration levels down to about $2 \cdot 10^4$ cm^{-3} was observed from late evening through night. A size-resolved decay rate of 0.03 min^{-1} which accounts for air exchange rate as well as for deposition rate, was reported in literature for particles in the 0.02-1 μm size range (Chao et al., 2003).

The concentration levels measured in the sitting room (N = 420) were lower than those in the kitchen: an average concentration level on the order of $1 \cdot 10^4$ cm^{-3} was determined as the diurnal room-background and in the order of $7.5 \cdot 10^3$ cm^{-3} as the nocturnal room-background. A decreasing trend in the concentration levels was observed during the night, down to a concentration of about $6 \cdot 10^3$ cm^{-3} around 6 AM registered just before the wake-up hour. The effect of Environmental Tobacco Smoke (ETS) in the room was clearly visible given the sharp and fast rise observed in concentration levels immediately after cigarette lighting, reaching peak concentrations in 10-15 minutes. The additional contribution from ETS to the sitting room background concentration levels is represented in the box-plot of Figure 1. Regardless of the background level, the emission associated with 1-person-cigarette-smoke resulted in an increment in the concentration levels up to $3.1 \cdot 10^4$ cm^{-3}, with overall concentration peaks usually on the order of $1.6\text{-}2.5 \cdot 10^4$ cm^{-3} but also up to $4\text{-}5 \cdot 10^4$ cm^{-3} when a second cigarette was smoked shortly (i.e.: time elapsed less than 1 hour) after the first one. Similar to what is observed for cooking activities, an exponentially decreasing time pattern was observed after the concentration peak, but with a decay rate about 2 orders of magnitude higher.

The average concentration levels measured in the university office (N = 400) were in the order of $1.5 \cdot 10^4$ cm^{-3}, within a rather wide range from $3.7 \cdot 10^3$ to $8.6 \cdot 10^4$ cm^{-3}; similar values have been reported for an office in downtown Milano (Cattaneo et al., 2009). In the laser printer room (N = 85) the average concentration level was slightly higher ($1.5 \cdot 10^4$ cm^{-3}) but the range was much narrower ($1.9 \cdot 10^4$-2. $1 \cdot 10^4$ cm^{-3}), since movements in the room were limited compared to the office.

Short measurement campaigns were also performed in several microenvironments open to public. The related concentration data is summarized in Figure 1: in particular, concentration levels in a café (N = 33) were observed to range between $9.3 \cdot 10^3$ cm^{-3} and $5.9 \cdot 10^4$ cm^{-3}, with an average of $2.7 \cdot 10^4$ cm^{-3}; those measured during church service with incense burning (N = 26) were between $2.3 \cdot 10^4$-$2.6 \cdot 10^4$ cm^{-3} with an average of

$3.5 \cdot 10^4$ cm^{-3}; those measured in a ladies hairdresser salon at busy time (N = 147) ranged from $9.3 \cdot 10^3$ to $3.8 \cdot 10^5$ cm^{-3}, with an average of $9.6 \cdot 10^4$ cm^{-3}, and those measured in a supermarket (N = 40) ranged between $2.8 \cdot 10^3$-$1.0 \cdot 10^4$ cm^{-3} and presented an average concentration of $5.2 \cdot 10^3$ cm^{-3}.

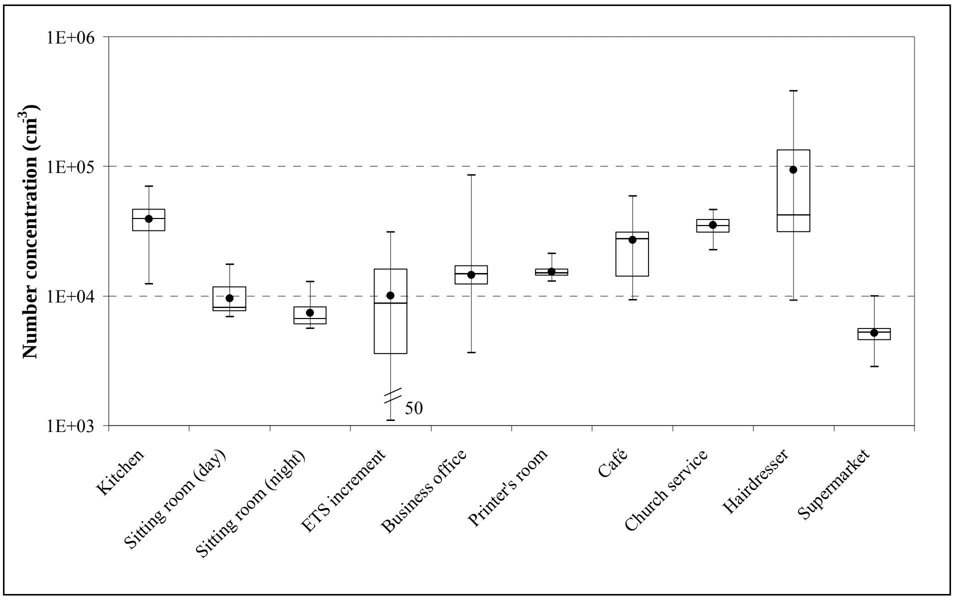

Figure 1 – Indoor microenvironments: summary statistics of 1-min number concentration data (black dot: average; white box: interquartile range; line: median; whiskers: min-max range).

3.2 Transport microenvironments

The concentrations measured during short pedestrian routes in the university campus area (N = 48) ranged between $1.4 \cdot 10^4$ and $5.7 \cdot 10^4$ cm^{-3}, with an average of $2.9 \cdot 10^4$ cm^{-3}. Obviously, the concentration level depends strongly on route features: an average concentration of 10^5 cm^{-3} was reported for walking through the city centre in Milano, including a tract on an inner-ring-road curbside (Cattaneo et al., 2009), whereas concentrations in the order of 3-$4 \cdot 10^4$ cm^{-3} have been reported for pedestrian routes of different subjects in the urban area of Milano (Schlitt et al., 2008). Car rides from the university campus to the city outskirts on rush hours (N = 160) resulted in a moderate exposure averaging about $2.3 \cdot 10^4$ cm^{-3} but with peaks up to $9.4 \cdot 10^4$ cm^{-3}. Though depending on several factors (e.g.: route features, traffic intensity, indoor car isolation), these values are in agreement with those reported for car rides in Milano, ranging between 5-$8 \cdot 10^4$ cm^{-3} (Schlitt et al., 2008), but are largely lower than the average concentration around 10^5 cm^{-3} reported for rides on the inner-ring-road in Milano (Cattaneo et al., 2009). Concentration levels similar to those in the car microenvironment have been measured during subway rides in the city centre of Milano (average: $4.3 \cdot 10^4$ cm^{-3}; N = 60) as well as during commuting train rides (average:

$3.0 \cdot 10^4$ cm^{-3}; N = 230), in substantial agreement with data reported for another subway line in Milano (Cattaneo et al., 2009).

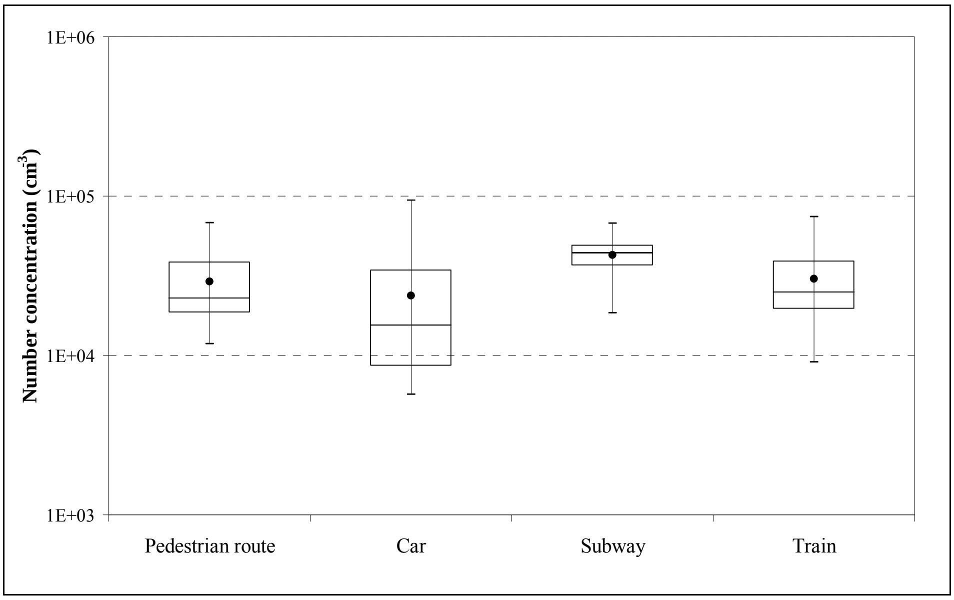

Figure 2 – Transport microenvironments: summary statistics of 1-min number concentration data (black dot: average; white box: interquartile range; line: median; whiskers: min-max range).

4. Conclusions

The measurements of the particle number concentration in the 20-1000 nm size range at different indoor microenvironments pointed out that average concentration levels were usually in the order of $1.0\text{-}4.0 \cdot 10^4$ particles cm^{-3}. At home, the highest concentration was measured in the kitchen, with large fluctuations essentially depending on the type of cooking activity; lower concentration levels and smaller fluctuations were observed in other rooms, with daytime levels about 30% higher with respect to nighttime levels.

Environmental tobacco smoke provided a significant additional contribution, up to $3.1 \cdot 10^4$ particles cm^{-3}, to indoor concentration levels. Concentration levels slightly higher than home-indoor were measured in other indoor microenvironments, especially in the hairdresser salon. The investigated transport microenvironments displayed concentration values rather similar, with respect both to the average concentration (about $3.0 \cdot 10^4$ particles cm^{-3}) and the maximum values (around $7.0 \cdot 10^4$ particles cm^{-3}, but up to about $1.0 \cdot 10^5$ particles cm^{-3} for the car).

Based on average concentration values measured in various microenvironments and according to a time-weighted exposure scenario, a daily averaged exposure of $1.6 \cdot 10^4$ particles cm^{-3} for people commuting in Milano is estimated. Indoor home exposure provides about 46% of the total daily exposure, indoor office exposure for about 30%

and transport environments exposure adds the remainder (24%), almost insensitive to the transportation mode. The effect of one smoker in the home results in an increase in the contribution of home indoor source up to about 60% of the total. Though limited to relatively short campaigns and to particular microenvironments, these results are in agreement with literature data and point out the dominating role of the indoor exposure to fine and ultrafine particles. However, further monitoring campaigns, especially concerning different transport modes, are still required in order to strengthen and generalize these very first results.

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