In-Cabin and Ambient Measurement of Nanoparticles during Urban Driving

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Introduction

A European worker spends on average 3 hour per week commuting (Pascal Paoli and Damien Merllié, 2000), mostly by car or public transport (Schwanen, 2002). Air quality in the vehicle's cabin is affected by exhaust gases, both gasoline and diesel, from surrounding vehicles (Briscoe, 2000). Especially for particulate pollution, nanoparticles have a significant role on human health effects (Oberdörster, 1994). The scope of this work is to assess in-cabin nanoparticle concentration levels, by utilizing a mobile laboratory (Konstandopoulos et al., 2008). The study was completed in the region of Thessaloniki, Greece, including urban, industrial and suburban areas. It was also conducted during summer and winter periods.

Measuring platform description

The mobile laboratory (MOBILAB) has been built on a Mercedes-Benz Sprinter van. The van provides a 4.3 m length, 1.8 m width and 1.9 m height for the load compartment, as well as 1.25 ton cargo weight. The tailpipe emissions meet the Euro IV regulations. The emission control system includes a Diesel Oxidation Catalyst (DOC) and a Diesel Particulate Filter (DPF). Options that were necessary for the unhindered operation of the instruments, such as additional air conditioner for the load compartment, GPS antenna, high capacity battery, stronger power generator, etc. have also been installed. The vehicle is shown in Figure 1.

Figure 1: The MOBILAB vehicle.

Modifications were required to transform the van into a mobile measuring platform. The load compartment has been divided into two sections, to provide sound and heat insulation for the instruments and their operators. In the front and larger compartment, special racks and shelves have been installed, to support the instruments. The equipment is crash-test checked and certified, to be in compliance with regulations for on-board installation. All the acquired instruments have been placed and secured on shelves. In addition to the instruments, the Data Acquisition System (DAS) has been installed on a 19-inch rack. Moreover, an Uninterruptible Power Supply (UPS) unit has been installed. All instruments and the DAS were connected to electricity through the UPS. The UPS' batteries can provide the necessary power to the instruments for several minutes or hours (depending of the instrumentation that is operating) before the power generator needs to be turned on. The vehicle's air-conditioning system provides the required working temperature in this compartment. The required power is supplied by a power generator (5.5 kW) installed in the rear compartment. All equipment was mounted on anti-vibration rubber bushes and thus decoupled from the vehicle's chassis. The front compartment of the vehicle equipped with several instruments is shown in Figure 2.

Figure 2: The front compartment of the van with the gas and particle measurement instruments.

Instrumentation and sampling description

The on-board instrumentation includes gas analyzers for air pollution monitoring (CO, NO_X, SO_2), an FTIR analyzer for the measurement of exhaust gases and a series of particle measurement instruments. These instruments include a Condensation Particle Counter (CPC) for number concentration, a Scanning Mobility Particle Sizer (SMPS) for size distribution, a Micro-Orifice Uniform Deposition Impactors (MOUDI) for mass concentration based on particle size and a Diffusion Size Classifier (DiSC) for number concentration and average diameter. The instruments used in this study are listed in the following table.

Table 1: Instrumentation utilized in the current study.

Parameter	Instrument	Measurement range	Response time
In-cabin particulate monitoring equipment			
Number concentration	DiSC (Diffusion charger)	20-200 nm	2 s
Ambient particulate monitoring equipment			
Number concentration + Size distribution	SMPS 3936 (3080L + 3775)	10-370 nm	120 s
Ambient gas pollutants monitoring equipment			
NO, NO_2, NO_X	APNA 370 (chemiluminescence)	0.5 ppm	<120s

An isokinetic sampling probe was installed on the roof of the vehicle and was used by the SMPS and the NO_X analyzer. The sampling tubes were from conducting material to avoid particle losses due to static electricity. The in-cabin particle concentration was measured by the DiSC, placed on the instrument rack and sampling freely from the cabin. The height difference between the sampling probe and the vents of the vehicle's cabin is about 1.5m. Figure 3 illustrates the equipment and sampling installation.

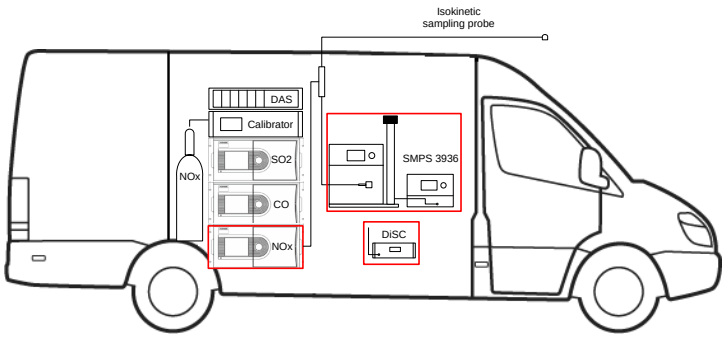

Figure 3: Equipment and sampling illustration of MOBILAB

Prior to the measurement campaigns, a comparison between the SMPS and the DiSC was performed in the Aerosol and Particle Technology Laboratory (APTL), using a soot particle generator (CAST). This cross-checking of both instruments showed very satisfactory results in various concentration levels. Thus the results of the ambient and the in-cabin measurements can be compared, even though two different techniques were employed. As already mentioned DiSC was used for the in-cabin particle monitoring. The choice of this instrument was based on future studies that will be performed with other types of vehicles, were space is important. Moreover this instrument can be operated by battery, with no requirements in other power supply. It is therefore suitable for on-road measurements with any type of vehicle. The correlation between SMPS and DiSC can be seen in Figure 4.

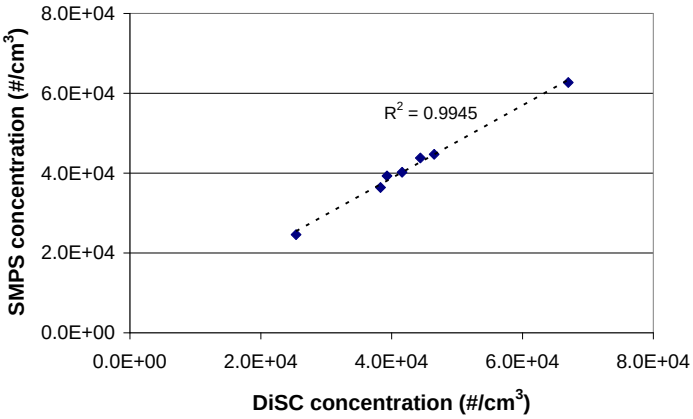

Figure 4: Correlation of SMPS and DiSC instruments.

Location and time frame of measurement campaign

The greater area of Thessaloniki was covered during the study. The covered area was divided in four (4) regions: Center, Ano Poli, East and West. The 'Center' region is approximately the city center of Thessaloniki, where mostly commercial activities take place and traffic is heavier than any other area. 'Ano Poli' is an area close to the center, but mainly residential and in a higher altitude than the center. Less traffic is present in this area, however the streets tend to have more inclination (greater slope) and therefore higher engine loads which can contribute to greater particle concentrations. The 'East' region is a primarily residential and densely populated. Finally, the 'West' region includes the industrial area of the city, along with some residential areas. Traffic there is usually lower than in other regions, but during working hours, many heavy duty vehicles are traveling because of the nearby industrial zone. In Figure 5 a map of Thessaloniki is presented with the measuring routes of MOBILAB and the four regions.

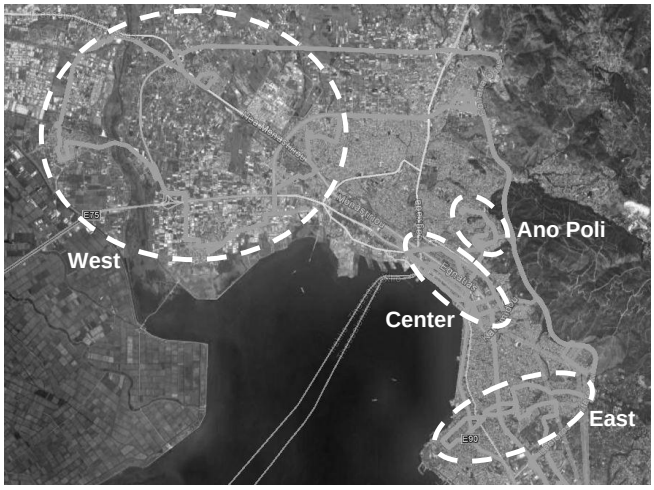

Figure 5: Map of Thessaloniki

The campaign was separated in two sets of measurements; summertime and a wintertime set. The summertime set commenced on the 22nd of August 2011 and was completed on the 2nd of September, while the wintertime set lasted from the 13th until the 24th of February 2012. One week in each set was dedicated for the 'Center' and 'Ano Poli' regions and the second week for the 'East' and 'West' regions. Measurements were conducted on a certain route and repeated several times both during morning and afternoon hours. A steady state of conditions in the vehicle was maintained during the whole measuring campaign. The vehicle's windows were shut while the air conditioning system operated in such a way as to keep the temperature in the interior constant at approximately 22°C.

Results

The in-cabin nanoparticle concentration follows the overall trend of the concentration out of the vehicle (External). Usually, the in-cabin values are lower than the external ones whilst indicating a short delay. Furthermore, when the in-cabin concentration reaches a peak, it takes longer for the value to decrease, than the external value. A typical measurement of both concentration levels is presented in Figure 6.

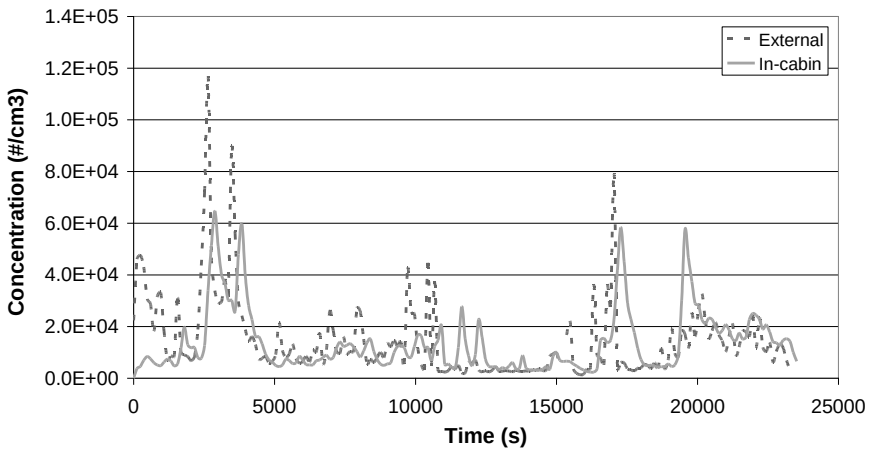

Figure 6: Typical external and in-cabin particle concentration measurement.

In some cases the in-cabin concentration levels reach much higher values than external concentration levels and again it takes longer to decrease. The effect of an external emitting source can be more significant inside the vehicle, than the effect it has on the particle concentration of ambient air. These cases are more frequent when the traffic is heavier. Most probably due to the traffic ahead of the vehicle and the proximity of the emission source (i.e. exhaust pipe) to the vehicle's air vents. Figure 7 is an example of such a case.

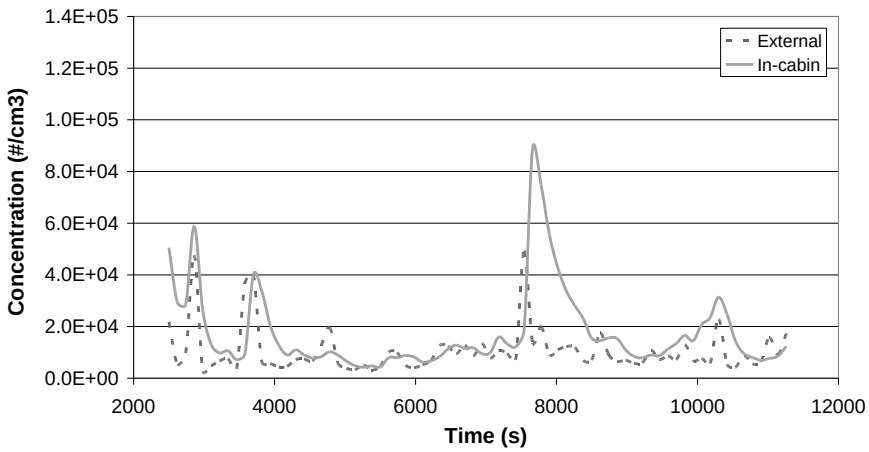

Figure 7: Higher in-cabin concentration in heavy traffic.

Summer and winter period external average particle number concentrations are comparable for all four regions of Thessaloniki (Figure 8, 9). However, there is approximately a 10% drop during winter period at the East and West regions. This may be attributed to the reduced traffic resulted from the financial crisis and the elevated gas prices for winter 2012 compared to summer 2011. The highest particle number concentrations can be seen in the 'Center' area. This is normal due to more dense traffic of diesel vehicles emitting nanoparticles such as buses and taxis. 'Ano Poli' region has slightly lower values than 'Center' whereas 'East' and 'West' have approximately 30% lower particle number concentrations. The region of 'Ano Poli' also shows these high external concentration values, despite the much lower traffic observed in comparison to the 'Center', due to the steep roads (high engine loads) in the area which probably contribute to this, as well as the proximity to the city center.

Generally, the in-cabin particle number concentrations appear to be lower than the external values showing that the cabin filter is effective. It is also evident that the differences between in-cabin and external values are smaller during the wintertime.

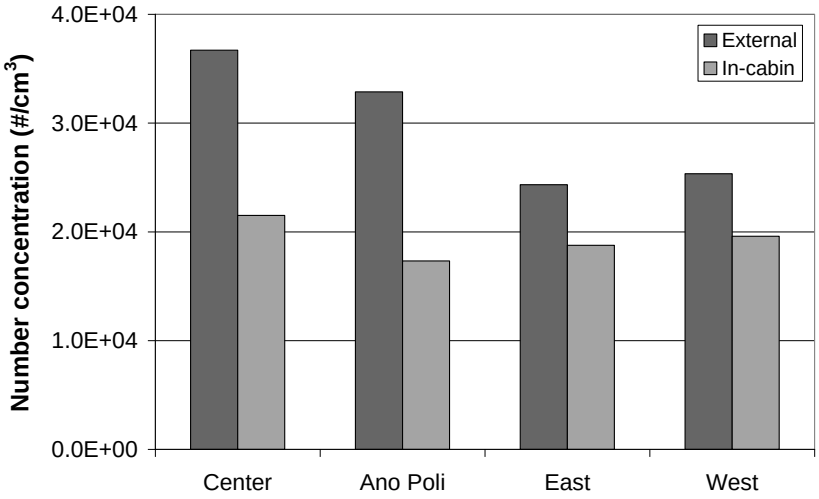

Figure 8: Average particle number concentrations for summer period per region.

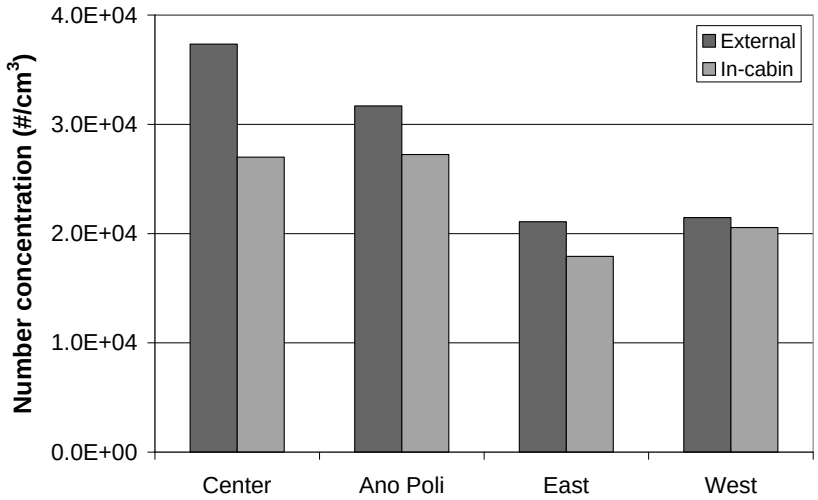

Figure 9: Average particle number concentrations for winter period per region.

Conclusions

The in-cabin nanoparticle concentrations follow, albeit with some delay, the external concentration trend. However, the in-cabin values are dependent on the traffic conditions whilst the external values are dependent both on traffic and weather conditions. During the wintertime the external particle number concentrations are decreasing as they are effected by the weather conditions (e.g. wind, rain), while the in-cabin remain unaffected, resulting in a reduction of their in between difference.

Previous studies in Thessaloniki have shown higher concentration of nanoparticles during the winter season (Pimenidis et al., 2008), especially in the East and West parts of the city. Residential heating in the winter season contributes to the increase in concentration levels. This study shows different results. The financial crisis has been a significant factor for the decrease of traffic, during the past months, in Thessaloniki and it may also be the reason for this unexpected result, since the wintertime measurements were completed last. This indicates also that the most important factor for the in-cabin air quality is the surrounding vehicles, especially the ones in front, and not remote sources, like residential heaters.

Finally, the results indicate that future work on the cabin filter's technology can improve its efficiency. This matter in conjunction with further and more frequent measurement campaigns all around the year can constitute a more conclusive study.

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