Concentrations of ultrafine particles and NO_x inside a car while driving

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Contents

Summary

Vooral rondom drukke verkeerswegen is de luchtkwaliteit relatief slecht. Dit wordt grotendeels veroorzaakt wordt door de uitlaatgassen van de passerende voertuigen. Bekend is dat de blootstelling aan dergelijke verontreinigde lucht kan leiden tot gezondheidseffecten op de korte en lange termijn. Op basis van gereguleerde metingen in stedelijk gebied kan deze blootstelling geschat worden. Veel minder goed bekend is de blootstelling van inzittenden in een rijdend voertuig op de weg. De vraag hoeveel deze blootstelling is, is vooral van belang voor degenen die beroepsmatig veel achter het stuur zitten zoals bestuurders van personenvervoer (taxi's, bussen) en (internationaal) vrachtvervoer.

Om hier een beter inzicht in te krijgen is de luchtkwaliteit gemeten in een rijdend voertuig. Tijdens deze campagne zijn de verkeerscomponenten NO_x en ultrafines gemeten in het (rijdende) voertuig en vlak daarbuiten. Naast het vergelijken van de gemiddelde concentraties buiten en binnen is het effect van de verschillende ventilatiemodes op de kwaliteit van de lucht in het voertuig bestudeert.

De voornaamste bevinding is dat het luchtfilter in het voertuig de aantallen stofdeeltjes reduceert tot ca. 45% van de waarden direct buiten het voertuig. Dit is overigens nog steeds boven de achtergrondwaarde in een stedelijk gebied. Alleen in het geval van recirculerende lucht is sprake van ontkoppeling: de concentraties in het voertuig dalen na verloop van tijd tot minder dan 10% en laten geen invloed zien van wat er buiten gebeurt.

Voor NO en NO_2 zijn de niveaus binnen vergelijkbaar met buiten indien er geventileerd wordt. In geval van recirculatie neemt de NO_2 in het voertuig een relatief stabiele waarde aan; deze is min of meer vergelijkbaar met de gemiddelde waarde buiten. Het filter blijkt dus geen effect te hebben op het terugdringen van NO_x in het voertuig.

Recirculeren van lucht in een voertuig kan slechts voor beperkte tijd omdat na verloop van tijd de ramen zullen beslaan door ophoping van vocht en vanwege het te hoog worden van de CO_2-concentratie. Men is dan gedwongen de ramen te openen waardoor alsnog (verontreinigende) lucht van buiten wordt aangevoerd.

1

Introduction

While driving, vehicles emit nitrogen oxides (NO and NO_2) and particulate matter (PM) leading to substantially higher levels of pollution along heavily-trafficked roads. Epidemiological studies describe a number of adverse health effects associated to the short- and long-term exposure to both components.

But what about the exposure of the driver *inside* a car while driving around? Such a question is particularly relevant for those spending many hours in vehicles due to their profession (like cab and truck drivers). Compared to the exposure in an urban area, much less information is available here. One of the first studies addressing this question was presented by Morin (2009). He concluded, rather qualitatively, that a "*car cabin does not protect the driver from air pollution*". The study presented here was carried out to give further quantitative evidence for such a conclusion. The investigation here involved one vehicle. Resulting data may be different in case of other types of vehicles. However, the implications of the findings of this study will be at least indicative for the exposure inside cars in general.

2

Experimental setup

The vehicle used in this study was a Volkswagen Touran, a small van with sufficient space in the back to contain the measuring instruments. Concentrations NO_x and particle number were measured at two places. One air inlet was positioned at the front of the car (fixed to the grill). It was bent backwards to avoid blockage by road material and to avoid aerodynamic effects (Figure 1). A second inlet was near the driver's head in order to obtain an estimate of the concentration levels inside the car.

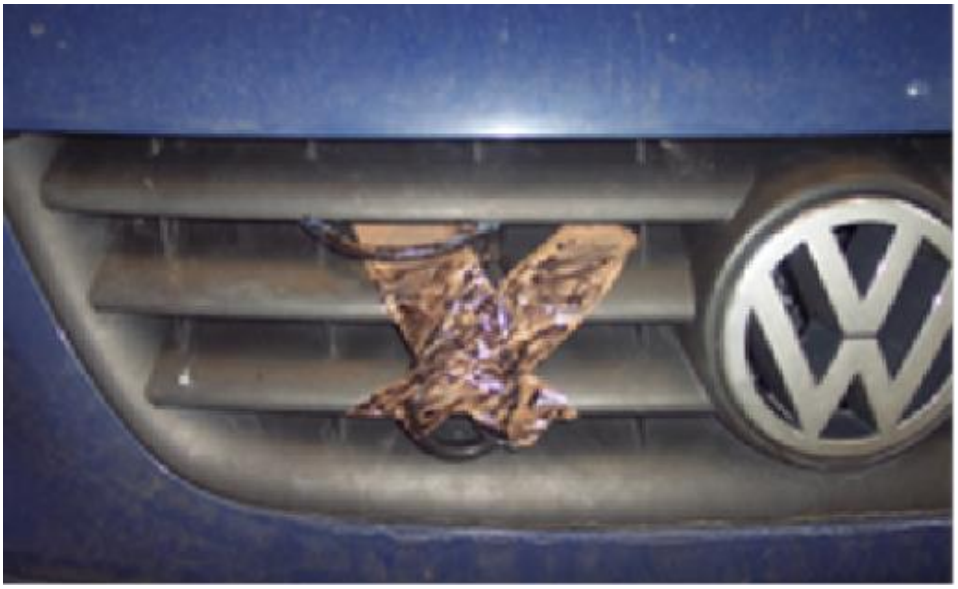

Figure 1: Position of the inlet at the front of the car

Two NO_x monitors (with data loggers) were positioned in the rear (Figure 2). Two (handheld) particle counters were on the bottom before the passenger seat in the front and connected to a laptop that was logging the data (on the seat) (Figure 3).

Figure 2: The two NO_x monitors and computers logging the data

Figure 3: Handheld particle counters and a laptop logging the data

The ventilation system present in the Touran is the HVAC system: 'Integrated Heating, Ventilation and Air Conditioning system'. In our experiment the position of the ventilation grid was fixed, directing the flow towards the driver.

The air cabin filter (Figure 4) is essentially a dust pollen filter. No specification has been given by the manufacturer other than that it: "eliminates most pollutant particles such as fumes, bacteria, pollen and dust that come into your car". As can be seen in the figure the filter has been blackened due to the presence of soot particles. Soot is mostly

found on very tiny particles called 'ultrafines'. Their characteristic diameter range is less than
0.1 µm.

The collection efficiency of a pollen filter is normally at a minimum around 0.2-0.4 µm (see Figure 5). Particles smaller or larger than this minimum are expected to be filtered out by (at least) 50%.

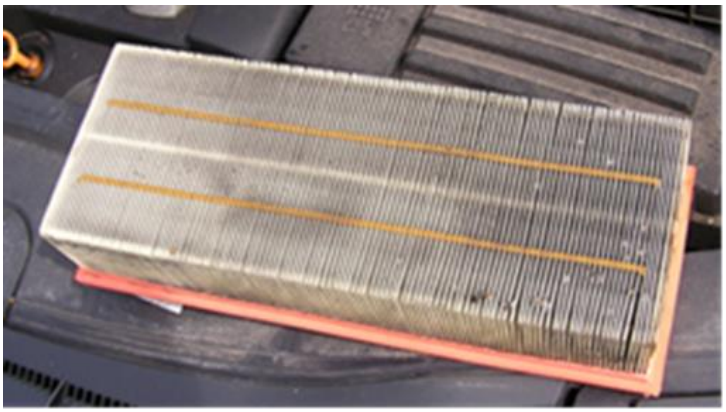

Figure 4: The air cabin filter in the Touran

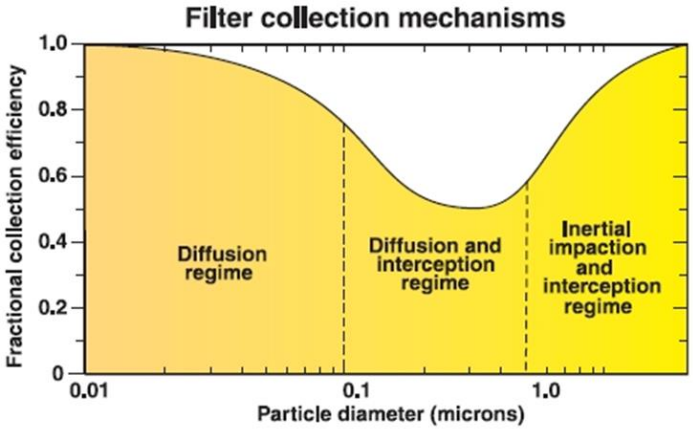

Figure 5: Collection efficiency of a pollen filter

3 Results

Measurements were carried out for in total sixteen hours on four different days. Results shown here are for one day, but they are also representative for the remaining days.

3.1 Ultrafine particle numbers

3.1.1 Time series

The number of particles simultaneously measured inside and outside the driving vehicle were compared for different modes of ventilation. The entire period given in Figure 6 took one hour and the ventilation rate was set to mode 2. As can be observed, the numbers measured outside the car on the road (just in front of the car) reaches peak levels as high as 250 000 cm^{-3}. Such levels indicate measurements directly behind another car, often while standing in a queue before a traffic light or during the acceleration phase after the traffic light turns green.

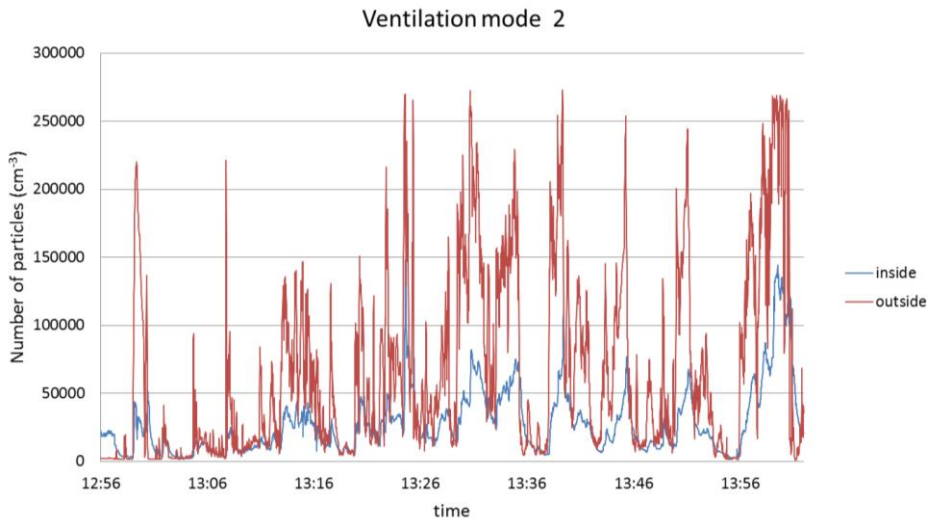

Figure 6: Number of particles in cm^{-3} inside (blue) and outside (red) the car at a fixed ventilation rate (mode 2)

The temporal correspondence between the two signals is obvious. The particle number concentrations inside is systematically lower than that outside the car. At some periods the baselines of both the signals agree, indicating that there is no transport of polluted air from outside (due to the absence of traffic sources).

At a lower ventilation rate (mode 1) less air enters the compartment per time unit. The particle numbers inside the car (Figure 7) behave rather similar to those acquired when ventilation rate was set to mode 2. The striking feature for mode 1 is the time delay observed in the series inside the car compared to that outside the car. This time delay is probably caused by the slower entrance of air and, by consequence, the mixing of (outside) air into the car's compartment will take more time.

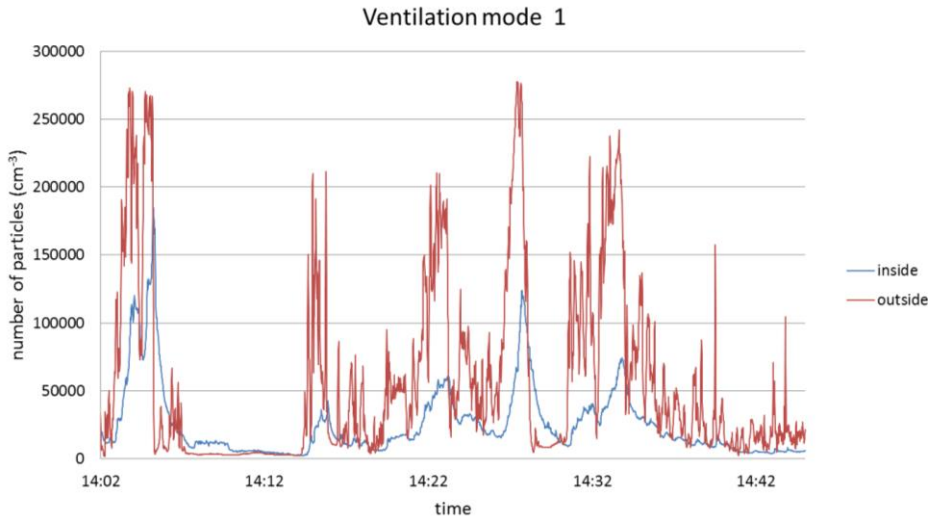

Figure 7: Number of particles (in cm^{-3}) inside and outside at a lower ventilation rate (mode 1)

When the ventilation system is set to the recirculation mode no outside air enter the cabin and the air inside will pass through the cabin's filter repeatedly. Clearly, the particle concentration levels inside decrease to very low values and show very low variability (Figure 8). The two signals actually largely decouple, although at some moments a very small contribution of outside air is still visible in the signal inside the car. This indicates that outside air possibly enters the vehicle through cracks or fissures.

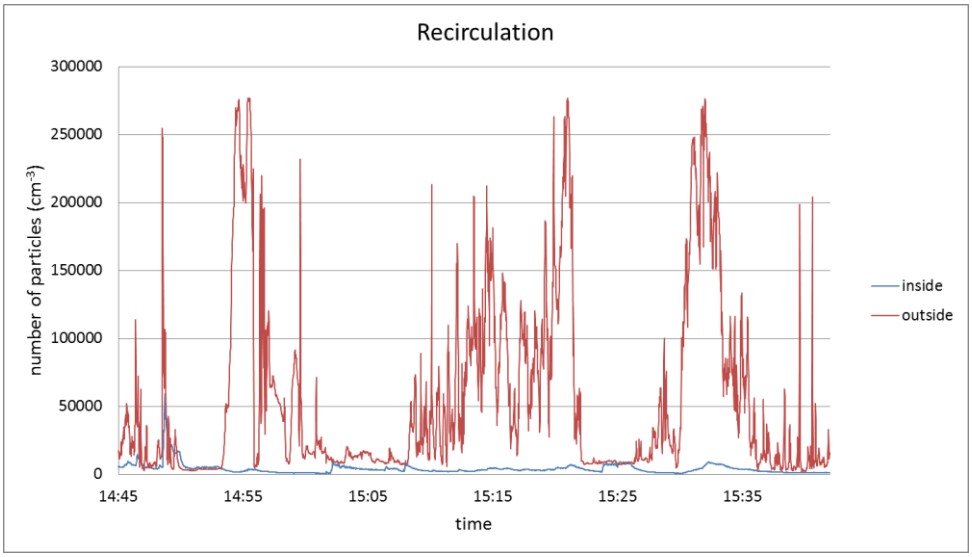

Figure 8: Number of particles in cm^{-3} inside and outside during the *recirculation mode*

3.1.2 Averages

The average results of the one hours of measurement for the particle numbers are presented in Figure 9 and Table 1. For all three modes particle numbers inside the car are lower than those measured outside the car. On average, number concentrations inside do not differ largely if ventilation mode 2 or 1 is applied: levels inside are 50-60% of those measured outside. However, reduction is above 90% when the recirculation mode is used. Apparently, the cabin's filter eliminates high numbers of particles in this mode, which is due to the fact that inside air passes through the filter repeatedly.

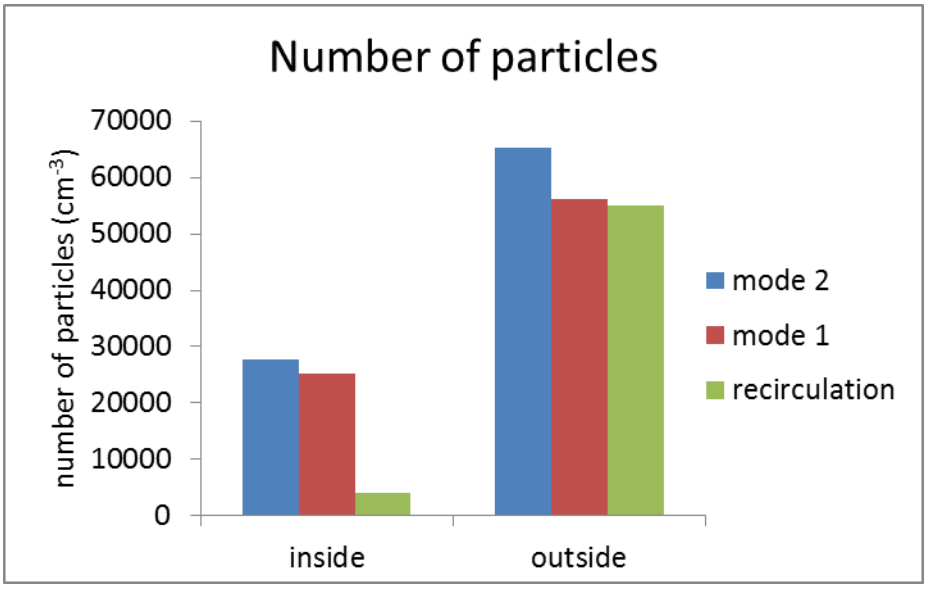

Figure 9: Average number of particles in cm^{-3} inside and outside while applying modes 2,1, and recirculation

Table 1: Average number of particles in cm^{-3} and ratio inside/outside for the different modes

	inside	outside	ratio
mode 2	27828	65358	0.43
mode 1	25186	56210	0.45
recirculation	4027	55058	0.07

3.2 Nitrogen oxides

3.2.1 Time series

In Figure 10 the simultaneous measurements of NO and NO_2 outside and inside the car during ventilation mode 1 ,2, and recirculation are shown. With modes 1 and 2, a very close correspondence between the two signals is visible. There is some indication for a very small time delay for the signal inside the car compared to that outside. Apparently, the cabin's filter does not affect the NO gas molecules present in the air that is transported into the car. In the recirculation mode, the rapid variation seen in the outside concentration signal is not observed inside the car. However, the baseline levels agree rather well, indicating that air inside is still influenced by the air outside the car but at a slow rate (which was also observed in the case of particle numbers).

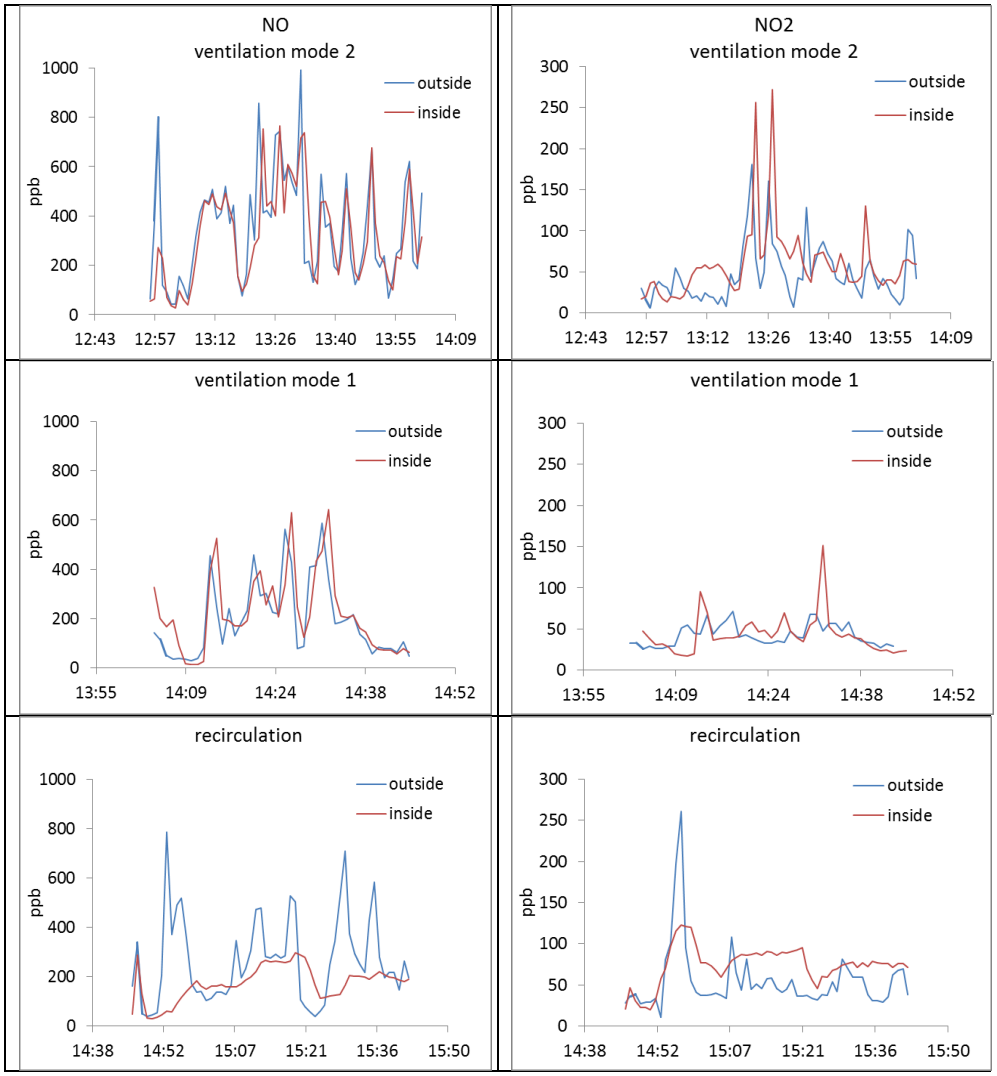

Figure 10: NO (left) and NO_2 (right) time series inside and outside during ventilation mode 2 (top), 1 (middle), and recirculation (bottom)

The correlation between the two NO_2 signals is much weaker than for NO. In the atmosphere, and likely also in the cabin's car, a large part of NO_2 will be produced after a reaction with O_3 which explains the stronger dissociation between the signals. In the recirculation mode, signals again decouple. Inside the car, signal levels appear to converge to some stable level which can be expected after sufficient mixing of air in the cabin and no influx of outside air.

3.2.2 Averages

The average results for NO and NO_2 are given in Figure 11 and Table 2.

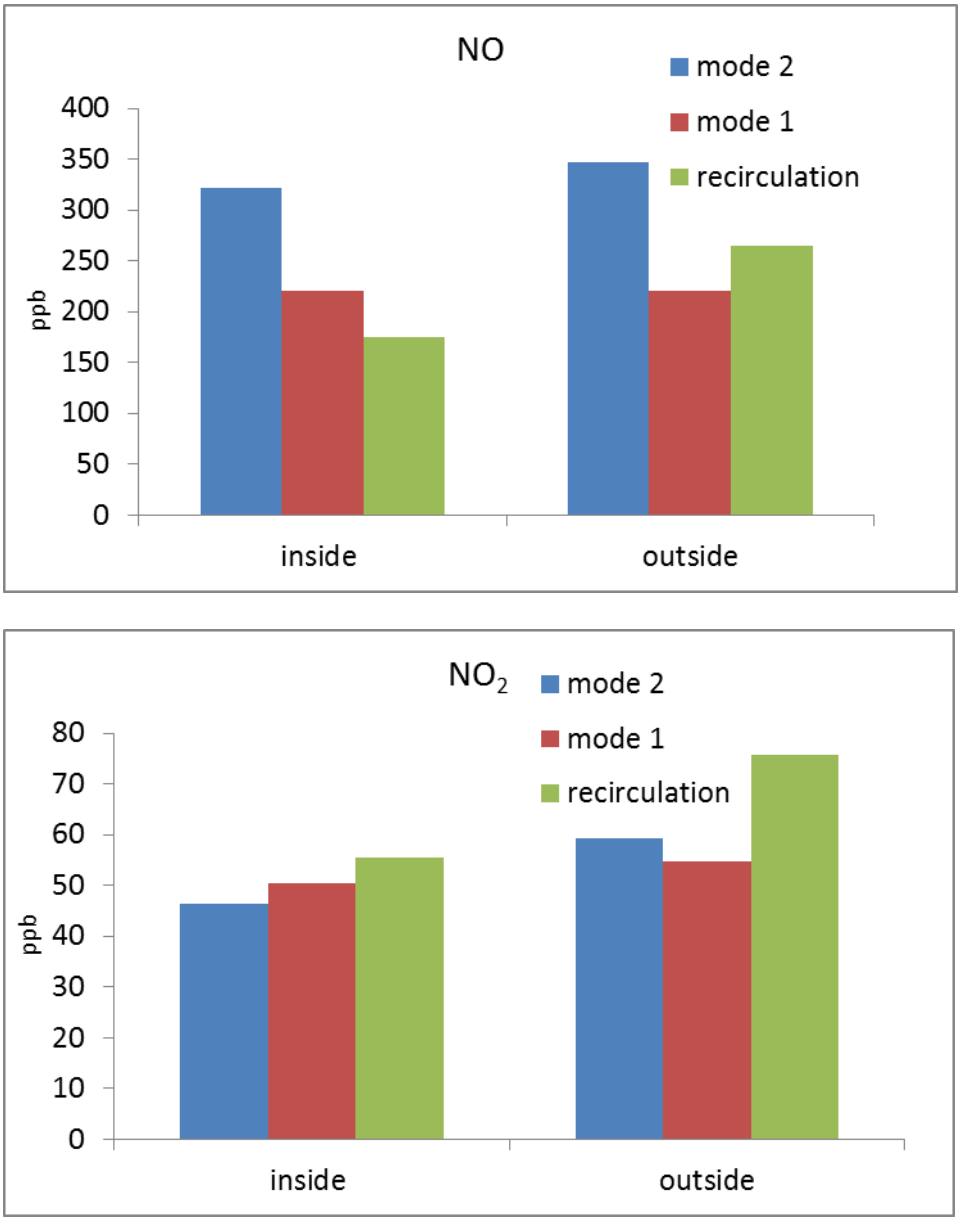

Figure 11: Average concentrations for NO (top) and NO_2 (bottom) inside and outside the vehicle and during different ventilation modes

Table 2: Average concentrations for NO (top) and NO_2 (bottom) in ppb and ratio inside/outside

NO	inside	outside	ratio
mode 2	321	347	0.9
mode 1	221	220	1.0
recirculation	175	264	0.7

NO_2	inside	outside	ratio
mode 2	46	59	0.8
mode 1	50	55	0.9
recirculation	55	76	0.7

The main observation is that during ventilation the ratio 'inside vs outside air' for NO (and NO_2) levels tend to be near one: the effect of the cabin's filter is small if not negligible. On average, the NO and NO_2 levels inside the car during the recirculation mode are roughly two-third of those outside the car. The concentrations of the air inside that car have a rather stable appearance, i.e. are not affected by peak events in the outside air.

4

Conclusions

NO and NO_2 concentrations measured inside the vehicle while driving are rather similar as those observed on the road just in front of the car. This implies a direct exposure of the driver to periods or events of high concentration levels occurring on the road. Particle number concentration levels appear substantially lower (by some 45%) when using ventilation mode, but they are still well above the average urban background levels. Only in the case of recirculating the air in the car's cabin, the number concentrations decrease substantially (to less than 10% of the outside level). When using this mode, the NO_x concentrations in the cabin appear rather stable and unaffected by the NO_x levels outside the car.

The first finding of this study is that setting a car's ventilation system to "recirculate" is the best (and only) way to reduce the driver's exposure to particulate matter. It is for this reason that in California it has been officially advised to use the recirculation mode (with windows closed) while being in traffic jams. However, when using this mode car's windows can be fog up after 10-15 minutes depending on the meteorological conditions (Figure 12). In addition, the CO_2 level in the car will also increase (possibly leading to less alertness). Opening the windows is then required to have an unobstructed view (and less CO_2) thereby enhancing the exposure to polluted air again.

Figure 12: Windows in a car fogged up due to lack of ventilation

The second finding is that the cabin's filter does not protect from exposure to sometimes elevated levels of NO_x observed on the road. Needless to say, the best way to reduce exposure while driving is to avoid being in traffic jams (Figure 13).

Figure 13: Traffic jam during rush hour at the Interstate 10 in Los Angeles.

5
Reference

Morin J.P. (2009): *The exposition of vehicle drivers to toxic air contaminants in French cities*, 13th ETH Conference on Combustion Generated Nanoparticles, Zurich.

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