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Driver exposure to air pollution inside a car – effects of ventilation method

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Abstract

The main objectives of the study presented here were to assess the effects of the ventilation method on air pollution inside the car, and to derive recommendations aimed at reduction of driver and passengers exposure to air pollution.

Experiments were carried at various traffic conditions, during all working days of the week, 7 AM - 7 PM. Concentrations of CO, NO, NO_2, PM10, PM2.5 and PM1 were measured, over total travelled distance of more than 4,000 km.

Analysis of the collected experimental results allowed comparison of internal air pollution for various ventilation methods, assessment of continuous driver exposure to high levels of air pollution for these ventilation methods, evaluation of vehicle age influence on air pollution inside a car, etc. Effects of smoking on air pollution levels were also studied.

Keywords*: driver exposure, air pollution inside a car, ventilation mode.*

Introduction

It is quite well established now that road users, such as cyclists and especially drivers and passengers, are exposed to higher levels of air pollution than background or curbside data might suggest, Chan et al (1991), Colwill and Hickman (1980), Kingham et al (1998), Rudolf (1994),Van Wijnen et al (1995), Taylor and Fergusson (1998). According to the latter source, road users in the centre of the roadway are likely to be travelling through a tunnel of the most polluted air and this is the principal reason for their raised relative exposure to pollutants.

Despite the fact that ventilation of a vehicle was noted as possibly affecting the level of internal air pollution, Taylor and Fergusson (1998), according to authors' knowledge, there is still lack of detailed studies dealing with the effects of the ventilation mode on air pollution levels inside a car. Chan et al (1991) have performed very limited number of VOC and CO measurements at few ventilation modes. The mode with air conditioning (AC) switched on and introduction of outdoor air into the car was not studied.

In countries with hot climate conditions, the majority of the vehicle fleet is equipped with AC systems, and the driver usually makes a decision about the desired method of car ventilation: without air conditioning and opened window, with AC and internal recirculation of air, or with AC and introduction of outdoor air into the car. Car ventilation by introduction of outdoor air with the AC switched-off and windows closed is also used sometimes.

1 - Objectives

The main objectives of the study presented here are to assess the effects of the ventilation method on air pollution inside the car, and to derive recommendations aimed at reduction of driver and passengers exposure to air pollution.

2 – Methodological approach

The research methodology included a survey, aimed at collection of data on vehicle ventilation "behaviour" of drivers and experimental measurements of air pollution inside cars.

Target pollutants

Concentrations of CO, NO, NO_2, PM10, PM2.5 and PM1 were measured in this study. Interscan gas analyzers of models 4140, 4540 and 4150 with electrochemical cells served for measurements of CO, NO and NO_2 concentrations, respectively. Particulates concentrations were measured by the GRIMM 1.107 PM meter that allowed simultaneous measurement in the PM10, PM2.5 and PM1 size ranges.

Vehicles tested

Seven cars of different ages participated in the tests. They were divided into two groups: so called "new" vehicles with mileage accumulated not exceeding 25,000 km and so called "old" vehicles with mileage of 150,000 km or more. The cars are listed in Table 1.

Car model	Production year	Mileage, km	Doors No.	Saloon type	Tests group
Toyota-Yaris	2005	6,000	5	Hatchback	New
Peugeot-206	2002	23,000	5	Hatchback	New
Peugeot-307	2002	25,000	5	Hatchback	New
Suzuki-Baleno	1998	150,000	4	Sedan	Old
Renault-Express	1994	190,000	3	Minivan	Old
Renault-Clio	1994	260,000	5	Hatchback	Old
Subaru EA71	1993	338,000	5	Station wagon	Old

Table 1: Vehicles tested in the study.All the vehicles that participated in experiments are typical of the Israeli fleet. They were checked and found to meet the requirements of Directive 2003/27/EC for in-service emission testing.

Testing routes

All tests were carried out in the Haifa region on two pre-selected routes representing different traffic conditions. The first route, 3.6 km length, representing downtown urban driving conditions, is characterized by relatively high traffic volumes, low average speed (measured to be about 22 km/h) and flat topography. The second route is an 11.6 km length segment of a main road on the northern entrance to Haifa, characterized by very high traffic volumes (two times more than in the downtown), moderate average speed (measured to be about 41 km/h) and zero road gradients.

Data collection and analysis

All readings of the gas analyzers and PM meter, as well as stop events, were logged at 0.33 Hz frequency by a Squirrel 1023 data logger and subsequently analyzed after downloading to a computer. Sampling collection was performed in the driver's breathing zone. Experiments were carried out on both testing routes during all working days of the week, 7 AM - 7 PM. Total travelled distance of more than 4,000 km was accumulated during the measurements, in order to ensure collection of sufficient experimental data. Experiments have been performed during summer – autumn period in Israel with ambient temperatures in the range 20-30 °C.

Testing program

The following car ventilation modes have been tested in the study:

1 AC switched on and introduction of outdoor air into the car (vent on), windows closed – "AC out";
2 AC switched on, internal air recirculation, windows closed – "AC rec";
3 AC switched off, vent on, windows closed;
4 AC switched off, vent off, window of the driver fully open – "Window open".

About 170 – 185 trips have been done with each ventilation mode. It is noted that no significant differences were found between results measured at modes (1) and (3). Therefore, only limited number of tests has been performed in mode 3, and these modes are not separated in the discussion hereafter.

3 – Results and discussion

Fig.1 presents results of comparison between average air pollution levels inside a car for different ventilation modes. The data appearing in the figure relate to the "old" cars group and were calculated as weighted average values for both tested routes together. Table 2 contains data with maximal observed values of pollutants concentrations for "new" and "old" car groups.

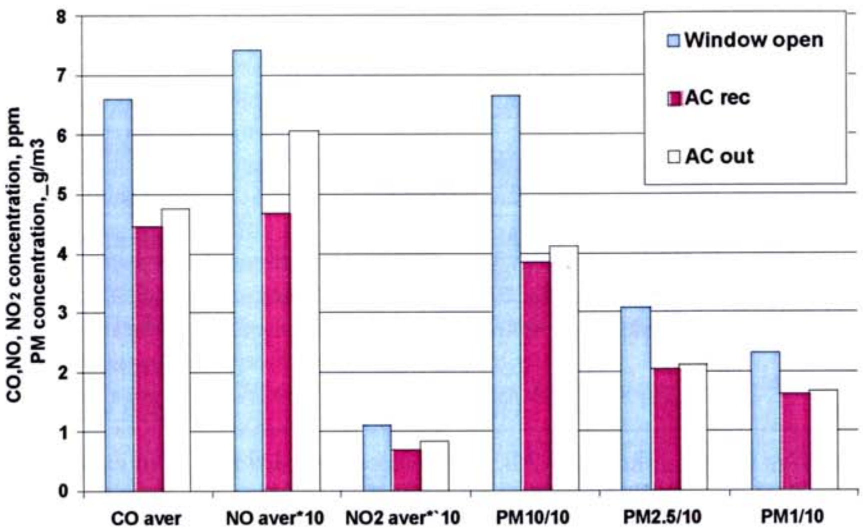


Figure 1: Ventilation mode effects on air pollution inside a car – "old" cars group.

As can be clearly seen from Fig.1, the highest values of air pollution for all measured pollutants were found for the "Window open" ventilation mode with AC switched off, vent off and fully opened driver window. The lowest internal air pollution levels were observed using the "AC rec" ventilation mode with air conditioning switched on, internal air recirculation and windows closed. A similar trend was found also for the "new" cars group. The differences measured between "AC rec" and "Window open" modes are statistically significant (p-values are less than 0.01 for all pollutants at 95%confidence level) and lie between 42 – 73% ("old" cars) and 22- 97% ("new" cars), dependent on pollutant type – see Table 3.

It is important to note that using "AC rec" ventilation mode results in some kind of "freezing" of air pollution levels inside a car: changes of pollutants concentrations become very slow – see Fig. 2. Therefore, it would be reasonable to use this mode only in clean environments: for example, highly ventilated road with low traffic volume, in order to prevent "freezing" of high air pollution levels inside a car for long exposure times.

Ventilation mode	Maximal measured values of air pollution inside a car											
	CO, ppm		NO, ppm		NO_2, ppm		PM_{10}, µg/m3		$PM_{2.5}$, µg/m^3		PM1, µg/m^3	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
AC on, recirculation, windows closed (AC rec)	16.6	20.1	1.3	1.45	0.15	0.23	65	122	30	43	26	37
AC on/off, vent on windows closed (AC out)	39	38	1.02	2.24	0.21	0.25	104	200	30.4	109	26	102
AC off, vent off, driver window open (Window open)	18.2	20	1.48	0.85	0.36	0.38	110	197	59	100	55	87

Table 2: Maximal measured values of internal air pollution.

Ventilation mode	Air pollution inside a car, %											
	CO		NO		NO_2		PM10		PM2.5		PM1	
	New	Old	New	Old	New	Old	New	Old	New	Old	New	Old
AC on, recirculation, windows closed (AC rec), reference case	100	100	100	100	100	100	100	100	100	100	100	100
AC on/off, vent on windows closed (AC out)	115	107	125	129	144	120	128	107	135	103	143	103
AC off, vent off, driver window open (Window open)	122	148	166	158	172	156	197	173	182	149	188	142

Table 3: Internal air pollution depending on ventilation mode.

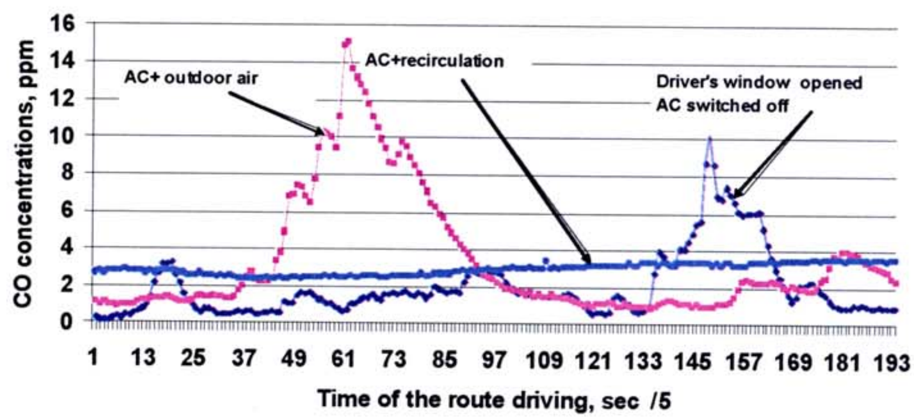


Figure 2: Example of internal CO concentrations for different ventilation modes – "new" car.

Distribution analysis of the measured air pollution levels inside a car shows (Fig. 3) that regarding NO_2 pollution, if the "Window open" ventilation mode is used, the driver and passengers are exposed to pollution levels higher than 1h limits of the Directive 1999/30/EC (0.2 mg/m3) during about 40 and 60% of the total driving time, for the "old" and "new" cars group, respectively. Driving in the "AC rec" or even "AC out" ventilation modes reduces by more than two times the duration of exposure to pollution levels higher than 1h limits of the Directive 1999/30/EC.

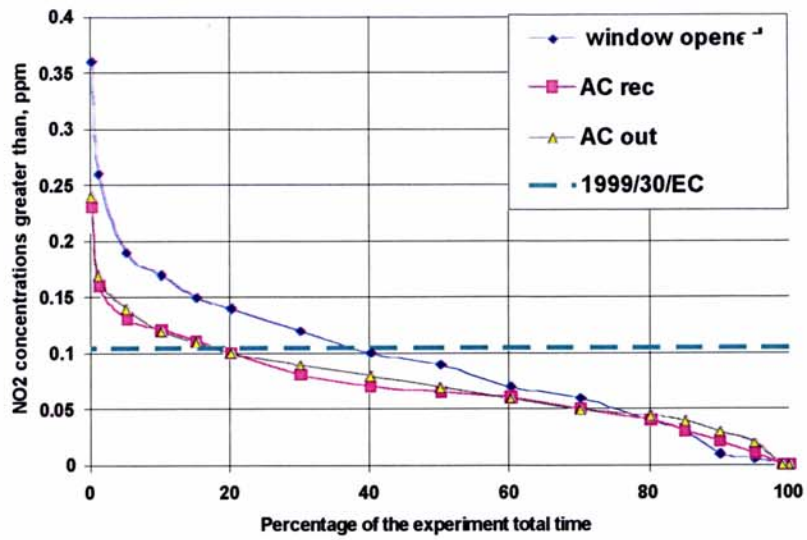


Figure 3: Distribution of internal measured NO_2 concentrations – "old" cars group.

Comparison of internal air pollution levels between "new" and "old" car groups is quite a challenging task, taking into account the large number of factors affecting ambient roadway concentrations of pollutants and the fact that no simultaneous measurements were performed with "new" and "old" cars. Available data do not show statistically significant changes in ventilation mode influence on gaseous pollutants concentrations between groups of different age – see Fig. 4 with an example of NO concentrations. The picture is somewhat different for PM concentrations – see Fig.5. As can be seen from this figure, the average measured PM10 levels in the "Window open" ventilation mode were higher by 17% for the "new" cars group, which most probably followed from higher ambient roadway PM10 concentrations. Despite this fact, in the "AC rec" mode for the "new" cars group, lower average PM10 levels by approximately 25% were measured. A possible reason for this could be the better sealing of new cars and, probably, higher efficiency of new air filtration systems. A similar trend was observed also for PM2.5 and PM1 concentrations. The changes observed are statistically significant – p-values are less than 0.01 at 95%confidence level.

Special series of experiments were carried out on a separate route without traffic (inside the university campus), in order to assess effects of smoking inside a car on driver exposure to air pollution. All these experiments were carried out only in "Window open" ventilation mode with two types of smoking: smoking out of the opened window (so called "passengers friendly smoking") and smoking inside the vehicle. The results are shown in Fig. 6. As can be seen, smoking inside the car leads to a dramatic increase in air pollution levels, especially, but not only, PM concentrations. In case of smoking "outside of the vehicle" (Fig. 6a), measured PM10 concentrations increased by 5 times and PM2.5 – by 8 times. It is noted that for this smoking pattern, ultra-fine particles PM2.5 reach above 90% of the total PM10. In case of smoking inside the car (Fig.6b), the observed PM levels were extremely high and approached 2400 μg/m3 (PM10) – almost 50 times more than the ambient 24h limit of the Directive1993/30/EC. Measured PM2.5 concentrations increased, as a result of smoking inside the car, by approximately 90 times and reach about 98% of the total PM10.

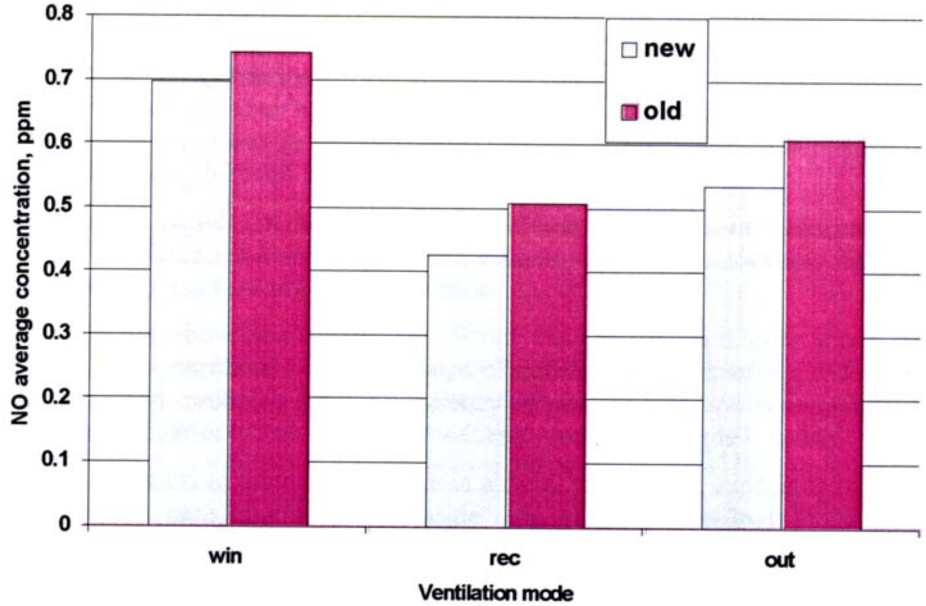


Figure 4: Comparison of average internal NO concentrations for "new" and "old" cars.

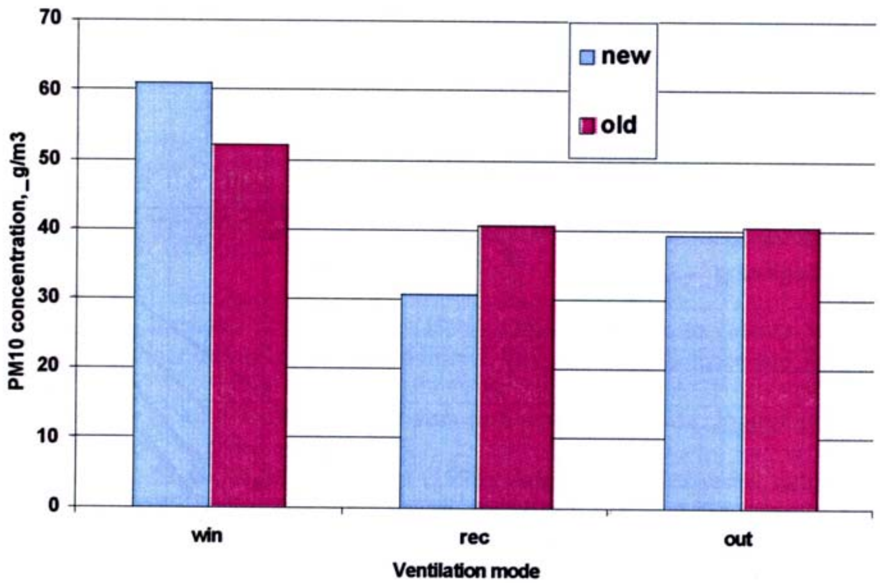
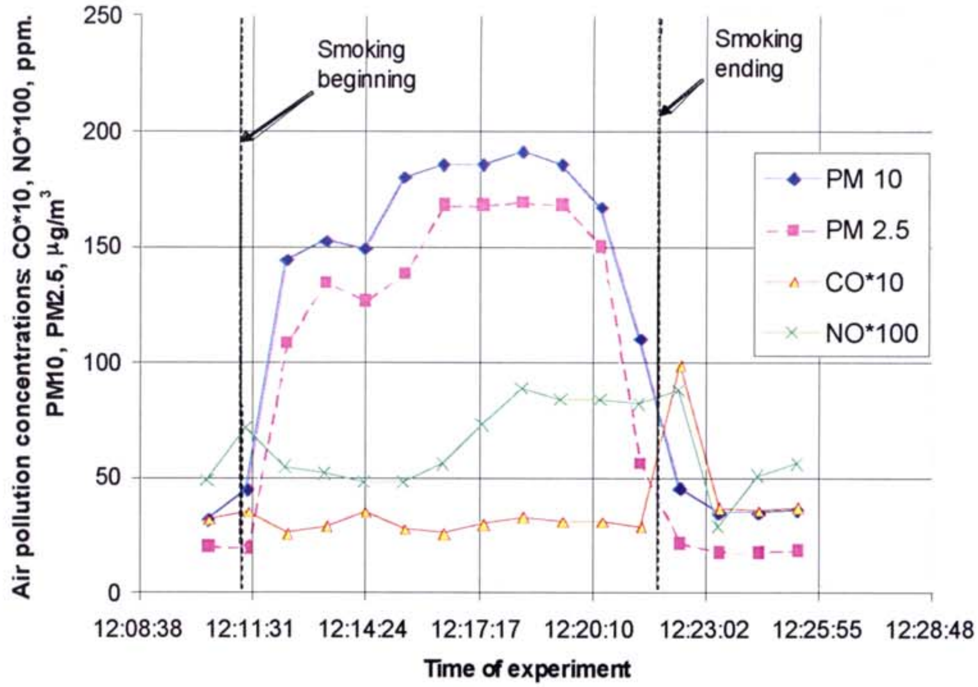
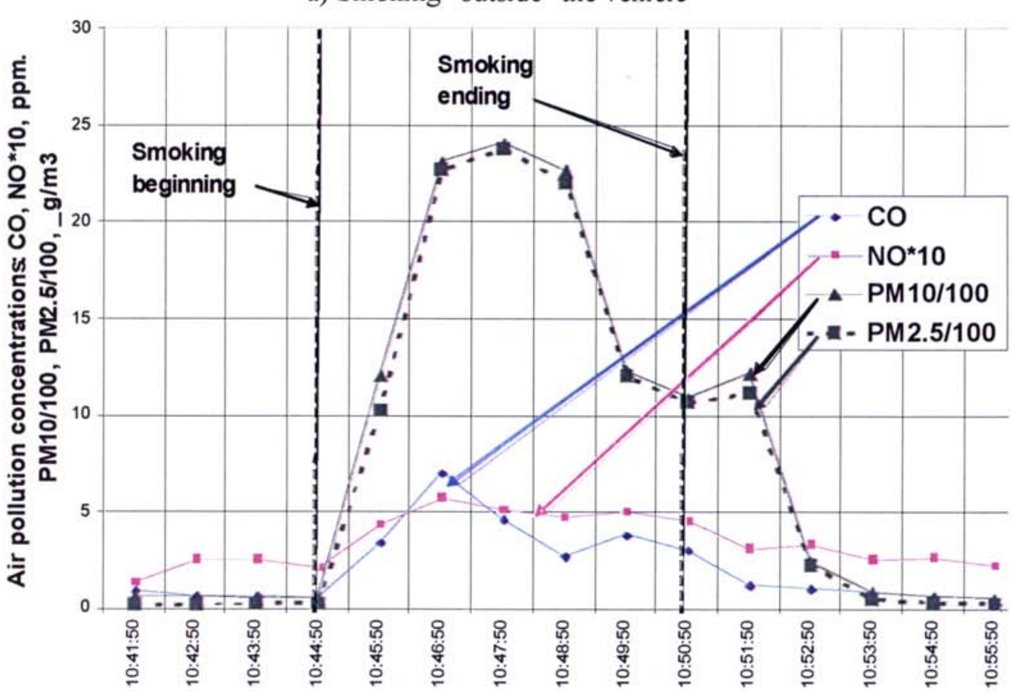


Figure 5: Comparison of average internal PM10 concentrations for "new" and "old" cars.



a) Smoking "outside" the vehicle



b) Smoking inside the vehicle

Figure 6: Effects of smoking inside the car on air pollution levels.

Conclusions

The highest values of air pollution for all measured pollutants were found for the ventilation mode with AC switched off, vent off and fully opened driver's window. The lowest internal air pollution levels were found at the ventilation mode with air conditioning switched on, internal air recirculation and windows closed. The differences between these modes were statistically significant (p-values are less than 0.01 for all pollutants at 95% confidence level) and lied in the range 42 – 73% ("old" cars) and 22 – 97% ("new" cars), dependent on pollutant type. The smallest changes (22 – 48%) were observed for CO concentrations.

It is recommended to switch on the "AC rec" ventilation mode only in clean environments: for example, highly ventilated road with low traffic volume, in order to prevent "freezing" high air pollution levels inside a car for long exposure times.

Measured data do not show statistically significant changes in ventilation mode influence on gaseous pollutants concentrations between groups of different age. Regarding PM pollution, better sealing of new cars and, probably, higher efficiency of new air filtration systems allow lower PM concentrations inside a car of lower age, if the "AC rec" ventilation mode is used.

Smoking inside a car leads to dramatic increase in air pollution levels, especially, but not only, PM concentrations. In the case of smoking "outside" the vehicle, measured PM10 concentrations increased by 5 times and PM2.5 – by 8 times. In the case of smoking inside the car, the observed PM10 levels were extremely high and approached 2400 µg/m3 – almost 50 times more than the ambient 24h limit of the Directive1993/30/EC. Measured PM2.5 concentrations increased, as a result of smoking inside the car, by approximately 90 times and reach about 98% of the total PM10.

It is noted that completion of the study by additional measurements of volatile organic compounds concentrations would definitely enrich the gained knowledge and would provide more information about the effects of different ventilation modes on driver and passengers exposure.

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