ORIGINAL ARTICLE

Personal exposure of Paris office workers to nitrogen dioxide and fine particles

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Aims: (1) To obtain an overall estimate of variability of personal exposure of Paris office workers to fine particles ($PM_{2.5}$) and nitrogen dioxide (NO_2), and to quantify their microenvironmental determinants. (2) To examine the role of potential determinants of indoor concentrations.

Methods: Sixty two office workers in a Paris municipal administration (all non-smokers) were equipped with personal samplers: passive samplers for 48 hours for NO_2 (n = 62), and active pumps for 24 hours for $PM_{2.5}$ (n = 55). Simultaneous measurements were performed in homes and offices; the local air monitoring network provided ambient concentrations. A time activity diary was used to weight measured concentrations by time spent in each microenvironment in order to estimate exposure concentrations.

Results: On average, $PM_{2.5}$ personal exposure (30.4 μg/m^3) was higher than corresponding in-home (24.7 μg/m^3) and ambient concentrations (16.7 μg/m^3). Personal exposure to NO_2 (43.6 μg/m^3) was significantly higher than in-home concentrations (35.1 μg/m^3) but lower than the background outdoor level (60.1 μg/m^3). Personal exposures to $PM_{2.5}$ and NO_2 were not significantly different from in-office concentrations. $PM_{2.5}$ and NO_2 personal exposures were not significantly correlated. In-home, in-office, in-transit, outdoor time weighted concentrations, and time spent in other indoor microenvironments explain respectively 86% and 78% of personal variations in $PM_{2.5}$ and NO_2. In-home $PM_{2.5}$ concentration was primarily influenced by exposure to environmental tobacco smoke, and secondly by the ambient level (R^2 = 0.20). NO_2 in-home concentration was affected mostly by the ambient level and gas cooking time (R^2 = 0.14).

Conclusion: While results show the major contribution of in-home and in-office concentrations to both NO_2 and $PM_{2.5}$ personal exposures, the identification of indoor level determinants was not very conclusive.

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In epidemiological studies, accurate estimation of exposure is important for evaluation of health risks. Assessment of exposure to air pollution is often based on fixed site measurements provided by the local air quality monitoring network. Because of economic and practical reasons, personal exposure measurements are rare in epidemiological studies.

In the 1980s personal exposure studies were carried out in the United States.[1–3] These studies first focused on gaseous pollutants such as nitrogen dioxide (NO_2), using passive samplers. Personal exposure to particulate matter (PM),[4–6] which requires a noisier and more bulky active sampler, was determined later. Studies were subsequently conducted worldwide,[7–31] but only a small number have been done in France.[32–34]

Personal exposure studies aim to assess the distribution of individual exposure, and to identify and quantify the contribution of different factors such as environmental tobacco smoke (ETS), cooking activities, outdoor concentrations, and traffic. In this context, outdoor and indoor levels are often determined at the same time as personal measurements. Because of practical difficulties, microenvironmental measurements generally take place at only one site: the home, workplace, or school. Moreover, few personal exposure studies have been carried out on randomised populations, especially for PM, which requires an important contribution from participants.

The objectives of this study were: (1) to obtain an overall estimate of variability of personal exposure to fine particles ($PM_{2.5}$) and nitrogen dioxide (NO_2) in a specific population of office workers living in the Paris metropolitan area; (2) to evaluate the relative contribution of different microenvironments to personal exposure by performing measurements in both the home and workplace; and (3) to examine the role of potential determinants of indoor concentrations.

MATERIALS AND METHODS

Study design

Personal and indoor NO_2 and $PM_{2.5}$ measurements were conducted simultaneously with the same devices. Indoor measurements were carried out in the home and workplace, the two microenvironments most frequented by city dwellers. Measurements took place from December 1999 to September 2000 (at the rate of two persons per week), and were supplemented by three questionnaires related to microenvironmental characteristics and time activity patterns.

Each participant was equipped with personal samplers for a period of 48 hours for NO_2 and 24 hours for fine particles. Outdoor concentrations during the measurement period were provided by the Paris air quality monitoring network.

Subject selection

The personal exposure study was conducted on Paris office workers recruited in a Paris municipality service in charge of social action, childhood, and health (DASES). A total of 200 subjects were selected by randomisation from the 2100 DASES office workers living and working in Paris or in one of the three peripheral departments covered by the regional air quality monitoring network. After excluding 60 smokers

Abbreviations: ETS, environmental tobacco smoke; PM, particulate matter; TWC, time weighted concentration (smoking status interfering with personal measurements), 140 workers were invited to participate. The order of participants was also determined by randomisation.

A sample size of at least 50 persons was previously determined, in order to be able to show a correlation between personal and outdoor measurements of more than 0.40, with $\alpha = 0.05$ and a power of 0.80. Because of the expected response rate (40%) and the necessity to exclude smokers whose proportion was estimated at one third, 200 subjects were sampled.

Sampling methods and analytical procedures

NO_2 measurements were taken from Monday to Wednesday, or from Wednesday to Friday, for 2884 ± 62 minutes (minimum 2595, maximum 3045). During personal measurements, the NO_2 badge (Ogawa & Co, Pompano Beach, Florida, USA) was attached to clothing near the breathing zone, while at night it was put on the bedside table. The passive sampler for residential measurement was placed 1.5 metres high in the home living room, and in the office. NO_2 was captured on a coated filter and measured by spectrophotometry ($\lambda = 545$ nm).

Personal $PM_{2.5}$ measurements were taken on the first day of the NO_2 measurements periods, for 1425 ± 80 minutes (minimum 1110, maximum 1680). For in-office $PM_{2.5}$ measurements, a timer was used, whereas in-home measurements were only taken when the subject was present at home; he had to turn the pump on when he arrived home and off when he left. The sampling times were respectively 617 ± 41 minutes (600 and 720 in a few cases) in the office, and 862 ± 195 minutes (minimum 510, maximum 924) in the home. $PM_{2.5}$ measurements were performed using a pump sampling air at a flow rate of 4 l/min (Gillian Instruments, model Gil-Air 5, Sensidyne, Clearwater, Florida, USA). Particles were selected by a GK2.05 cyclone KTL (BGI incorporated, Waltham, Massachusetts, USA) and collected on a filter (EMFAB TX40HI20-WW, Pallflex Putnam, Connecticut, USA). Flow rates were calibrated at the beginning and measured at the end of each personal and indoor measurement. The level of pump noise was reduced by placing the pump in a shell equipped with cork and rubber. During the day the shell was carried in a rucksack, facilitating movement during transport. During the night the personal sampler was located in the living room. Indoor $PM_{2.5}$ samplers were placed on a table or a desk in the home and in the office.

Particles were analysed by gravimetric method. A microbalance M5P (Sartorius Laboratoire, Palaiseau, France) with 1 μg reading precision, was used in a room where temperature (t) and relative humidity (RH) were controlled (t = 20±1°C, RH = 50±5%). Before and after sampling, all filters were weighed twice; when the difference between two consecutive weighings exceeded 4 μg, a third weighing was performed.

Twenty four hour outdoor $PM_{2.5}$ concentration was obtained from the only fixed urban background station equipped with a continuous $PM_{2.5}$ analyser (TEOM, R&P, New York, USA). Forty eight hour NO_2 concentration was the arithmetic average provided by the two (of 15) urban background stations respectively closest to the home and workplace and equipped with chemiluminescence analyser. Concentrations in different means of transport (car, subway, bus, bike) were estimated using data from a fixed monitoring traffic station located near the Paris ringroad.

Evaluation of exposure conditions

Three questionnaires were used to describe for each subject: (1) general characteristics of the residential and occupational environment (topographic situation, local traffic, heating and cooking system); (2) time activity diary with 15 minutes resolution; and (3) unusual exposure during measurements (exposure to ETS, cooking activities, etc).

Quality assurance

Results from $PM_{2.5}$ and NO_2 samplers were compared with respectively a TEOM analyser equipped with $PM_{2.5}$ cyclone and a chemiluminescence analyser at an outdoor site. The correlations were highly significant (Pearson correlation coefficient being respectively: $r = 0.96$ (n = 17) for $PM_{2.5}$, $r = 0.97$ for NO_2 (n = 49)). On average, the two series of measurements related to each pollutant did not differ significantly (13.9 *v* 12.8 μg/m^3 $PM_{2.5}$, 54.8 *v* 56.7 μg/m^3 NO_2).

NO_2 Ogawa samplers enabled all the measurements to be duplicated by placing one filter at each tip of the sampler. A good relation was observed between NO_2 duplicated measurements (n = 185; 41.2 *v* 41.3 μg/m^3, $p > 0.05$; $r = 0.92$), and the arithmetic mean of the duplicates was considered for each measurement. With regard to $PM_{2.5}$, it was not possible to ask participants to carry two pumps simultaneously. Thus only some indoor $PM_{2.5}$ measurements could be duplicated, showing a good repeatability, the deviations between duplications being less than 10% (n = 10; 24.7 *v* 23.8 μg/m^3, $p > 0.05$; $r = 0.87$). Moreover, in the Expolis study the authors duplicated several personal 48 hour $PM_{2.5}$ measurements using the same devices and obtained results of the same order: absolute average differences between duplicate results was 2.1 (SD 2.0) μg/m^3.[35]

Statistical analysis

Statistical analysis was performed with BMDP software (University of California). Results are expressed in terms of concentration (C) and time weighted concentration (TWC). For each microenvironment, TWC is the product of the concentration, measured or estimated, by time fraction spent in each microenvironment. The distributions of concentration, TWC, and their log transformed values, were tested for normality (Shapiro–Wilk test). Results are expressed as mean (SD), median, minimum, and maximum. Correlations between variables were estimated by Pearson or Spearman coefficients. Linear multiple regression was used to identify and quantify determinants of personal exposure and indoor concentrations. For each pollutant, two models of personal exposure were tested, the independent variables being concentration in the first, TWC in the second.

RESULTS

Population, living environment, and time activity patterns

The study sample consisted of 62 subjects for NO_2, and 55 subjects for fine particles, seven women having refused to carry the particle pump because of its noise and the weight of the rucksack.

All volunteers were non-smokers; there were 53 women, nine men. Mean age was 45.2 (10.0) years (minimum 23, maximum 61).

A small majority of subjects lived in Paris (56.4%), with 95.2% of subjects dwelling in an apartment with a mean surface area of 67.6 (28.1) square metres, the remainder living in a house. Exposure to tobacco smoke was not very frequent (11.3%) in the home. Around 60% of volunteers had a room directly exposed to traffic, moderate to heavy in 23 cases. A total of 22.6% of participants owned an individual gas heating system and 56.5% used a gas or mixed cooker.

All workplaces were located in Paris. Participants worked in an office with a surface area of 22.1 (10.0) square metres on average; 62.9% worked in an office that was either not or little exposed to traffic.

During the 24 hour $PM_{2.5}$ personal measurements, volunteers spent on average 21.7 hours indoors (home: 13.4 hours; office: 6.7 hours; other: 1.6 hours), 1.0 hour outdoors, and 1.3 hours in transport. The most frequently used means of transport were subway (39%) and walking (35%), followed by car (12%), bus (11%), and motorbike or bike (3%). One subject out of two was exposed to tobacco smoke (more than one cigarette

Table 1 Personal, indoor, and outdoor concentrations (µg/m^3)

	Personal exposure	Indoor home	Indoor office	Ambient
$PM_{2.5}$				
n	54	54	55	55*
Mean (SD)	30.4 (14.8)	24.7 (14.1)	34.5 (38.6)	16.7 (8.8)
Median	25.5	22.5	26.1	15.4
Minimum, maximum	14.6, 90.0	5.0, 106.4	4.7, 265.1	5.5, 55.9
NO_2				
n	61	62	62	62†
Mean (SD)	43.6 (11.3)	35.1 (13.7)	44.9 (16.0)	60.1 (15.2)
Median	43.5	32.5	44.0	58.9
Minimum, maximum	22.5, 85.0	14.0, 85.5	14.5, 104.0	25.4, 109.1

*From the local $PM_{2.5}$ station; †from NO_2 stations closest to home and workplace.

Table 2 Determinants of $PM_{2.5}$ personal exposure; multiple linear regression (n=53)

Independent variable	Reg coeff	Std err	Std reg coeff	p	R^2‡
*Concentration**					
C_H	0.701	0.069	0.67	<0.001	0.553
C_W	0.173	0.024	0.45	<0.001	0.781
C_O	0.278	0.115	0.17	0.02	0.804
TWC†					
TWC_H	1.205	0.103	0.66	<0.001	0.450
TWC_W	0.607	0.088	0.40	<0.001	0.686
Time in other indoor microenvironment	0.949	0.161	0.34	<0.001	0.793
TWC_T	1.791	0.450	0.23	<0.001	0.840
TWC_O	4.815	2.100	0.13	0.03	0.856

*C_H, in-home concentration; C_W, in-workplace concentration; C_O, background outdoor concentration.
†TWC_H, time weighted average concentration in home; TWC_W, time weighted average concentration in workplace; TWC_T, time weighted average concentration in transport; TWC_O, time weighted average concentration outdoors.
‡R^2 from the stepwise regression model.

a day). When subjects were equipped with the rucksack they spent less time in transport (–0.5 hour) than when they just wore the NO_2 passive sampler on the second day, but the difference was not significant ($p > 0.05$).

Distribution of personal exposure and microenvironmental concentrations

Most of the personal exposure, indoor and outdoor concentrations, and their TWC were log normally distributed. For both pollutants, as no difference in personal exposure was observed between people living in Paris and subjects living in suburbs, or according to season, all subjects were analysed together for the entire measurement period (December 1999 to September 2000).

Table 1 presents a summary of the results. Personal exposure to fine particles was significantly higher ($p < 0.0001$) than the in-home concentration, which was itself higher ($p < 0.0001$) than the ambient level. In offices, large variations in concentration were observed, with two very high measurements (265.1 and 162.7 µg/m^3 $PM_{2.5}$), as a result of intensive smoking during sampling. On average, personal exposure to NO_2 was not significantly different from occupational concentration, but was significantly higher than in-home concentration ($p < 0.001$) and lower than background outdoor concentration ($p < 0.0001$).

Cumulative exposures to $PM_{2.5}$ and NO_2, assessed by personal measurements (respectively 30.4 and 43.6 µg/m^3) were greater than the indirect estimates from time activity data and microenvironmental concentrations, the sum of the TWC being respectively 26.3 for $PM_{2.5}$ and 38.8 µg/m^3 for NO_2. It appears that home TWC (TWC_H; 13.7 µg/m^3 for $PM_{2.5}$ and 19.7 µg/m^3 for NO_2) and working TWC (TWC_W; respectively 10.1 and 12.3 µg/m^3) play a large part in cumulative personal exposure, whereas influence of transport (TWC_T; 2 and 6.3 µg/m^3) and outdoor TWC (TWC_O; 0.5 and 2.3 µg/m^3 respectively) is minor.

Despite a good correlation between NO_2 and $PM_{2.5}$ urban background levels ($n = 55$; $r = 0.69$; $p < 0.001$), no relation was observed between personal exposure to these two pollutants ($n = 53$; $r = 0.12$; $p = 0.38$). NO_2 and $PM_{2.5}$ concentrations were correlated neither in-home nor in-office (respectively $n = 54$; $r = 0.06$; $p = 0.69$, and $n = 55$; $r = 0.05$; $p = 0.74$).

Determinants of personal exposure

As the residuals of the model using non-transformed data were normally distributed, only non-transformed data were used.

The stepwise regression model showed that in-home, in-office, and outdoor concentrations explained 80% of variations in personal exposure to $PM_{2.5}$ (table 2). Using TWC, five variables—TWC_H, TWC_W, TWC_T, TWC_O, and time spent indoors other than in-home or office—contributed significantly to this personal exposure level (table 2). They explained 86% of personal exposure variations with a major contribution from TWC_H and TWC_W (69%), followed by time spent in other indoor microenvironments, and finally by in-transit TWC_T and outdoor TWC_O.

In-home, in-office NO_2 concentrations, and time spent in transport were the three variables selected in the stepwise multiple linear regression, and accounted for 75% of NO_2 personal exposure variations. Using TWC, the model including

Table 3 Determinants of NO_2 personal exposure; multiple linear regression (n=61)

Independent variable	Reg coeff	Std err	Std reg coeff	p	R^2‡
*Concentration**					
C_H	0.421	0.108	0.52	<0.001	0.631
C_W	0.342	0.124	0.21	<0.001	0.732
Time in transport	0.497	0.197	0.33	0.04	0.752
TWC†					
TWC_H	0.728	0.093	0.53	<0.001	0.482
TWC_W	0.971	0.157	0.43	<0.001	0.633
Time in other indoor microenvironment	0.494	0.120	0.27	<0.001	0.680
TWC_T	0.652	0.188	0.24	<0.001	0.724
TWC_O	2.454	0.716	0.23	<0.001	0.781

*C_H, in-home concentration; C_W, in-workplace concentration; C_O, background outdoor concentration.
†TWC_H, time weighted average concentration in home; TWC_W, time weighted average concentration in workplace; TWC_T, time weighted average concentration in transport; TWC_O, time weighted average concentration outdoors.
‡R^2 from the stepwise regression model.

Table 4 Determinants of $PM_{2.5}$ indoor concentrations in home (n=48) and office (n=42) not exposed to tobacco smoke; multiple linear regression

	In-home concentration					In-office concentration				
Independent variable	Coeff	Std err	Std reg coeff	p	R^2*	Coeff	Std err	Std reg coeff	p	R^2*
Ambient concentration	0.499	0.118	0.52	<0.001	0.265	0.407	0.196	0.32	0.04	0.154
Person density	118.015	62.337	0.24	0.02	0.334	–61.982	28.781	–0.32	0.04	0.199
Traffic proximity	1.676	0.877	0.23	0.03	0.391					

*R^2 from the stepwise regression model.

Table 5 Determinants of NO_2 in-home (n=62) and in-office (n=62) concentrations; multiple linear regression

	In-home concentration					In-office concentration				
Independent variable	Coeff	Std err	Std reg coeff	p	R^2*	Coeff	Std err	Std reg coeff	p	R^2*
Ambient concentration	0.258	0.108	0.29	0.02	0.07	0.556	0.125	0.52	<0.001	0.18
Using gas cooking†	0.068	0.037	0.23	0.03	0.14					
Floor height						–1.780	0.723	–0.30	0.02	0.24

*R^2 from the stepwise regression model.
†In minutes.

TWC_H, TWC_W, TWC_T, TWC_O, and time in other indoor microenvironments, did not really increase the coefficient of determination ($R^2 = 0.78$). However, all these variables were significantly associated with NO_2 personal exposure (table 3).

Determinants of indoor concentrations

Fine particles

Considering all the participants, including those exposed to ETS, in-home concentrations were influenced primarily by the number of cigarettes smoked in the home, and secondly by ambient concentration ($R^2 = 0.20$). In office buildings, the impact of tobacco smoke was higher ($R^2 = 0.95$) than in the home because of a larger number of sites with smokers (n = 13) and a higher smoking intensity, whereas the contribution from the outdoor level alone was very low (2%). We did not show the impact of any other factors.

In homes without ETS (n = 48), outdoor $PM_{2.5}$ level, person density, and local traffic were significantly associated with in-home $PM_{2.5}$ concentrations and explained 39% of their variation (table 4), mainly owing to outdoor concentrations. Cooking time and cleaning activity had no significant contribution. In offices not exposed to tobacco smoke (n = 42), the regression model showed a significant influence of outdoor level and person density. These factors explained 20% of in-office $PM_{2.5}$ concentration variations.

Nitrogen dioxide

A small part ($R^2 = 0.14$) of in-home NO_2 concentration variations could be explained by NO_2 ambient level and the time spent cooking with gas (table 5). The other factors such as ETS, local traffic, and floor height, did not have a significant influence. Twenty four per cent of variations in in-office NO_2 concentrations could be explained by two factors: outdoor level and floor height. There was an inverse relation between this last variable and in-office concentration (table 5).

Discussion

This study was carried out on a randomised sample of Paris municipal administration office workers; 85.3% were women, a percentage which does not differ from the DASES population composed of more than 80% women. The sex ratio in this administration is consistent with French statistics that indicate a high proportion of women in health social services (77.2%). The study sample can thus be regarded as representative of this field of activity.[36]

Our subjects spent a long time (approximately 90%) in indoor microenvironments. Time spent outdoors was low. A similar finding was observed by other teams,[6–8] especially Sexton and colleagues,[4] who reported that subjects from Waterbury stay indoors for a slightly higher percentage of the time (more than 94%).

Participation rate was consistent with those reported by other authors in such studies. Measurements were performed in satisfactory conditions for NO_2, and even for fine particles in spite of constraints related to the sampling device. For this reason measurements of personal exposure to $PM_{2.5}$ were limited to 24 hours.

A slight behavioural modification, also described by other authors,[9] was noted during our PM personal measurements. This modification could distort the personal exposure estimate, but has no effect on the study of exposure determinants. Nevertheless, technological progress to reduce the noise and bulk of the PM sampler could facilitate studies and decrease measurement bias.

Simultaneously with personal measurements, indoor measurements of fine particles were only recorded when subjects stayed in dwellings or premises used for professional purposes. This strategy accurately measured the indoor $PM_{2.5}$ concentrations to which subjects were exposed.

Conversely, passive samplers for NO_2 measurements were used continuously for 48 hours. Thus indoor concentrations reflect pollution throughout the entirety of the measurement period, even when participants were not present in their office or residence. Participants were not asked to block the passive sampler when they left the premises, in order to ensure good analytical sensitivity and to avoid mistakes and omissions.

Ambient levels were estimated from data provided by background stations of the Paris air quality monitoring network. Outdoor NO_2 concentration could be estimated accurately for each residence and workplace as a result of the high density of NO_2 stations. For $PM_{2.5}$, only one urban background station was equipped with a $PM_{2.5}$ analyser. This does not matter, however, as fine particle ambient distribution is spatially homogeneous in urban areas, as shown in Basel[37] and American cities.[38]

Our $PM_{2.5}$ results are consistent with levels reported in the literature, as shown by personal measurements: 30.4 for Paris office workers versus 24.3 μg/m^3 and 28.3 μg/m^3 respectively for adults and children in Amsterdam,[10 11], 21.6 μg/m^3 in Boston,[12] 24 μg/m^3 in Zurich,[8] and 21.9 and 36.7 μg/m^3 in Grenoble,[32] respectively in summer and winter. Indoor levels measured in Paris were 24.7 μg/m^3 in homes and 34.5 μg/m^3 in offices, whereas other teams have reported levels varying from around 17 μg/m^3 in Amsterdam classrooms and Boston homes to 23 μg/m^3 in Zurich homes, and 35.1 μg/m^3 in Grenoble homes during the winter period.

The level of personal exposure to $PM_{2.5}$ was greater than the in-home concentration, which in turn was higher than the ambient level during the same period. In previous studies this relation has already been described in healthy subjects,[4 5 9 13 14] whatever the considered particles (PM_{10}, $PM_{2.5}$, etc), even when ambient level is high.[14] Rojas-Bracho and colleagues[12] found mean personal $PM_{2.5}$ concentrations of individuals with chronic obstructive pulmonary disease to be lower than corresponding outdoor concentrations; they attributed these lower exposures to the low activity level of these patients. Sarnat and colleagues[15] also observed reduced personal exposure and indoor levels in comparison to outdoor concentrations in non-smoking older subjects, possibly because of limited exposure to indoor PM sources. Using TWC, our cumulative directly measured personal exposure is greater than indirect estimation. This difference, called "personal cloud" by Wallace,[38] has yet to be explained. Particulate matter resuspending, and exposure in buildings other than the home and workplace, such as canteens, restaurants, and shopping centres (not measured here), could contribute to this personal cloud. It must also be noted that exposure related to transport has not been measured, but only estimated from air quality data provided by a traffic site. Janssen and colleagues[9] have found that one hour spent in a vehicle increases personal PM_{10} concentration by 5.4 μg/m^3.

Most NO_2 studies[16–20 33] show the same relation: personal exposure is situated between indoor levels and outdoor concentrations. This relation is found in our population: on average, personal exposure (43.6 μg/m^3) is higher than in-home concentration (35.1 μg/m^3) but lower than ambient level during the same period (60.1 μg/m^3).

Compared to other personal exposure studies,[4 7 8 16 20 33] personal determinants are well identified and their weight is very high: they explain 86% of $PM_{2.5}$ variations and 78% of those of NO_2. For both pollutants, indoor TWCs are the major determinants of personal exposure. TWC_H and TWC_W explain 69% of $PM_{2.5}$ personal variations, and 63% of NO_2 variations. These proportions are the highest published in the literature, indoor concentrations accounting for 25–30%,[4] 34–46%,[7] or 50%[8] of variations in personal particulate exposure levels. TWC_T, TWC_O and time in other microenvironments increase our coefficient of determination in similar part for both pollutants. These very similar results for both pollutants are observed despite the fact that there is no correlation between NO_2 and $PM_{2.5}$ personal exposure or between NO_2 and $PM_{2.5}$ indoor concentrations. But it must be noted that the measurement times for both pollutants are different. This can also suggest that, as discussed later, indoor concentration determinants are different for fine particles and nitrogen dioxide. Contrary to this, outdoor sources for both pollutants do not really differ in the Paris area, where they are dominated by traffic emissions. Consequently a high correlation was observed between NO_2 and fine particles ambient levels. Sarnat and colleagues[15] noted an analogous phenomenon in Baltimore.

It should be noted that we were able to obtain good estimations of personal exposure from just the microenvironmental concentrations. Finally, the improvement in the determination coefficient associated with the use of TWC seems to be minor when compared to the difficulty of collecting accurate information about time activity patterns.

Identifying indoor concentration determinants in our study was more difficult, as $PM_{2.5}$ indoor concentrations are largely influenced by exposure to tobacco smoke. Even in our population, where this exposure was low in frequency and intensity, its influence was very strong, especially in offices. Our results are consistent with those of Phillips *et al* in several towns[21–28] and of Clayton and colleagues,[6] who showed that in a home with one or more smokers, PM individual exposure and indoor levels were significantly increased, even during the night. Wallace[38] and Janssen and colleagues[9] consider that one cigarette is responsible for a 24 hour increase of 2.3 μg/m^3 PM_{10} and 1–2 μg/m^3 fine particles respectively. When there is no exposure to ETS, in-home concentration is influenced by ambient level, person density, and proximity traffic (R^2 = 39%). In offices not exposed to ETS, two factors appeared to influence $PM_{2.5}$ concentration: ambient level and person density; these only explain 20% of the concentration. The person density, expressed as the ratio between the number of persons in the room and the surface area, can be regarded as a surrogate of particle resuspending. The negative borderline association between person density and in-office $PM_{2.5}$ concentration is rather surprising and could be caused by chance. Local traffic was not significant, perhaps because of the fact that the workplaces were not very numerous, with several participants working in the same building. Moreover, traffic was estimated by subjects themselves in four categories (zero, low, medium, heavy), and this appreciation is subjective and inaccurate. Although not significant in our model, cooking time and cleaning activity could also play a role. This contribution, shown by Clayton and colleagues[6] and Lioy and colleagues[14] for PM_{10}, has not been quantified for $PM_{2.5}$. However, Te Chang and colleagues[29] suggest that the high hourly $PM_{2.5}$ exposures they observed could be the result of fine particles emitted from grilling and other cooking activities.

Factors influencing NO_2 indoor concentrations are different from those observed for fine particles. We confirmed that gas cooking influences NO_2 in-home pollution, and using a precise questionnaire we were able to quantify the influence of time using the gas cooking. Usually, authors consider a dichotomous less accurate variable (gas cooking: yes/no).[17–20 30 31] In-home concentrations also depend on ambient levels as a result of exchanges between indoor and outdoor air, but no other factor could be identified. ETS did not have a significant contribution to NO_2 concentration. There are contradictory results in the literature about this influence.[18 30 33 34] An inverse relation was observed between in-office concentration and floor height, and we suppose that this factor could be a surrogate of traffic exposure, which is poorly evaluated by self reported car densities—living on a higher floor implying a lower exposure to traffic.

Building and furniture characteristics are important because they may influence NO_2 absorption, but we did not quantify this parameter.

Finally, a similar and primary contribution of indoor microenvironmental concentrations of both pollutants on personal exposure was observed in this study. Transport and outdoor exposure, on the other hand, play a secondary role in personal exposure, although outdoor air quality is indirectly implicated as a result of exchanges between interior and exterior NO_2 and fine particles. Identification and quantification of indoor determinants were not very conclusive, and merit further investigation.

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REFERENCES

1 **Dockery DW**, Spengler JD, Reed MP, *et al.* Relationships among personal, indoor and outdoor NO2 measurements. *Environ Int* 1981;**5**:101–7.

2 **Quackenboss JJ**, Kanarek MS, Spengler JD, *et al.* Personal monitoring for nitrogen dioxide exposure: methodological considerations for a community study. *Environ Int* 1982;**8**:249–58.

3 **Sexton K**, Letz R, Spengler JD. Estimating human exposure to nitrogen dioxide: an indoor/outdoor modeling approach. *Environ Res* 1983;**32**:151–66.

4 **Sexton K**, Spengler JD, Treitman RD. Personal exposure to respirable particles: a case study in Waterbury, Vermont. *Atmos Environ* 1984;**18**:1385–98.

5 **Spengler JD**, Treitman RD, Tosteson TD, *et al.* Personal exposures to respirable particulates and implications for air pollution epidemiology. *Environ Sci Technol* 1985;**19**:700–7.

6 **Clayton CA**, Perritt RL, Pellizzari ED, *et al.* Particle Total Exposure Assessment Methodology (PTEAM) study: distributions of aerosol and elemental concentrations in personal, indoor, and outdoor air samples in a southern Californian community. *J Expos Anal Environ Epidemiol* 1993;**3**:227–50.

7 **Carrer P**, Alcini D, Cavallo D, *et al.* Daily personal exposure to air pollutants of office workers in Milano. In: *Proceedings Healthy Buildings/IAQ 97, Vol. 2.* 1997:249–54.

8 **Monn C**, Fuchs A, Högger D, *et al.* Particulate matter less than 10 µm (PM_{10}) and fine particles less than 2.5 µm ($PM_{2.5}$): relationships between indoor, outdoor and personal concentrations. *Sci Tot Environ* 1997;**208**:15–21.

9 **Janssen NAH**, Hoek G, Brunekreef B, *et al.* Personal sampling of particles in adults: relation among personal, indoor and outdoor concentrations. *Am J Epidemiol* 1998;**147**:537–47.

10 **Janssen NAH**, de Hartog JJ, Hoek G, *et al.* Personal exposure to fine particulate matter in elderly subjects: relation between personal, indoor, and outdoor concentrations. *J Air Waste Manage Assoc* 2000;**50**:1133–43.

11 **Janssen NAH**, Hoek G, Harssema H, *et al.* Personal exposure to fine particles in children correlates closely with ambient fine particles. *Arch Environ Health* 1999;**54**:95–101.

12 **Rojas-Bracho L**, Suh H, Koutrakis P. Relationships among personal, indoor, and outdoor fine and coarse particles concentrations for individuals with COPD. *J Expos Anal Environ Epidemiol* 2000;**10**:294–306.

13 **Pellizzari ED**, Thomas KW, Clayton CA, *et al.* Particle Total Exposure Assessment Methodology (PTEAM): Riverside, California pilot study. US Environmental Protection Agency, Research Triangle Park 1993, EPA/600/SR-93/050, Volume I.

14 **Lioy PJ**, Waldman JM, Buckley T, *et al.* The personal, indoor and outdoor concentrations of PM_{10} measured in an industrial community during the winter. *Atmos Environ* 1990;**24B**:57–66.

15 **Sarnat JA**, Koutrakis P, Suh HH. Assessing the relationship between personal particulate and gaseous exposures of senior citizens living in Baltimore, MD. *J Air Waste Manage Assoc* 2000;**50**:1184–98.

16 **Spengler J**, Schwab M, Ryan PB, *et al.* Personal exposure to nitrogen dioxide in the Los Angeles Basin. *J Air Waste Manage Assoc* 1994;**44**:39–47.

17 **Noy D**, Brunekreef B, Boleij J, *et al.* The assessment of personal exposure to nitrogen dioxide in epidemiological studies. *Atmos Environ* 1990;**24**:2903–9.

18 **Monn C**, Brandli O, Schindler C, *et al.* Personal exposure to nitrogen dioxide in Switzerland. *Sci Tot Environ* 1998;**215**:243–51.

19 **Levy JI**, Lee K, Spengler JD, *et al.* Impact of residential nitrogen dioxide exposure on personal exposure: an international study. *J Air Waste Manage Assoc* 1998;**48**:553–60.

20 **Monn C**, Frauchiger P, Wanner HU. Assessment of personal exposure to nitrogen dioxide and ozone. In: *Proceedings of the 6th international conference on indoor air quality and climate, July 4–8, 1993, Helsinki, Finland, Vol. 3*, Indoor Air'93, Helsinki, 1993:319–23.

21 **Phillips K**, Bentley MC, Howard DA, *et al.* Assessment of air quality in Stockholm by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. *Scand J Work Environ Health* 1996;**22**:24.

22 **Phillips K**, Howard DA, Bentley MC, *et al.* Assessment of air quality in Turin by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. *Environ Int* 1997;**23**:851–71.

23 **Phillips K**, Bentley MC, Howard DA, *et al.* Assessment of air quality in Barcelona by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. *Environ Int* 1997;**23**:173–96.

24 **Phillips K**, Bentley MC, Howard DA, *et al.* Assessment of air quality in Paris by personal monitoring of nonsmokers for respirable suspended particles and environmental tobacco smoke. *Environ Int* 1998;**24**:405–25.

25 **Phillips K**, Bentley MC, Howard DA, *et al.* Assessment of environmental tobacco smoke and respirable suspended particle exposures for nonsmokers in Prague using personal monitoring. *Int Arch Occup Environ Health* 1998;**71**:379–90.

26 **Phillips K**, Bentley MC, Howard DA, *et al.* Assessment of environmental tobacco smoke and respirable suspended particle exposures for nonsmokers in Lisbon by personal monitoring. *Environ Int* 1998;**24**:301–24.

27 **Phillips K**, Howard DA, Bentley MC, *et al.* Measured exposures by personal monitoring for respirable suspended particles and environmental tobacco smoke of housewives and office workers resident in Bremen, Germany. *Int Arch Occup Environ Health* 1998;**71**:201–12.

28 **Phillips K**, Bentley MC, Howard DA, *et al.* Assessment of environmental tobacco smoke and respirable suspended particle exposures for nonsmokers in Hong Kong using personal monitoring. *Environ Int* 1998;**24**:851–70.

29 **Te Chang L**, Koutrakis P, Catalano PJ, *et al.* Hourly personal exposures to fines particles and gaseous pollutants—results from Baltimore, Maryland. *J Air Waste Manage Assoc* 2000;**50**:1223–35.

30 **Alm S**, Mukala K, Pasanen P, *et al.* Personal NO_2 exposures of preschool children in Helsinki. *J Expos Anal Environ Epidemiol* 1998;**8**:79–100.

31 **Quackenboss JJ**, Spengler JD, Kanarek MS, *et al.* Personal exposure to nitrogen dioxide: relationship to indoor/outdoor air quality and activity patterns. *Environ Sci Technol* 1986;**20**:775–83.

32 **Boudet C**, Zmirou D, Déchenaux J. Exposition personnelle aux particules fines (PM2.5) de la population grenobloise: l'étude européenne Expolis. *Rev Epidemiol Santé Publique* 2000;**48**:341–50.

33 **Saintot M**, Bernard N, Astre C, *et al.* Expositions au dioxyde d'azote et à l'ozone d'une population de l'Ile de France. *Rev Epidemiol Santé Publique* 2000;**48**:2S54–2S61.

34 **Bernard N**, Astre C, Vuillot B, *et al.* Measurement of background urban nitrogen dioxide pollution levels with passive samplers in Montpellier, France. *J Expos Anal Environ Epidemiol* 1997;**7**:165–78.

35 **Koistinen KJ**, Kousa A, Tenhola V, *et al.* Fine particle ($PM_{2.5}$) measurement methodology, quality assurance procedures and pilot results of the EXPOLIS study. *J Air Waste Manage Assoc* 1999;**49**:1212–20.

36 **Institut National de la Statistique et des Etudes Economiques (INSEE)**. *Les transports en 1998. Synthèses.* 36ème rapport de la commission des comptes des transports de la nation. Paris: INSEE, 1999.

37 **Oglesby L**, Künzli N, Röösli M, *et al.* Validity of ambient levels of fine particles as surrogate for personal exposure to outdoor air pollution—results of the European EXPOLIS-EAS Study (Swiss Center Basel). *J Air Waste Manage Assoc* 2000;**50**:1251–61.

38 **Wallace L**. Indoor particles: a review. *J Air Waste Manage Assoc* 1996;**46**:98–126.