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## **IMPACT OF THE URBAN POLLUTION ON THE INDOOR ENVIRONMENT - EXPERIMENTAL STUDY ON A MECHANICAL VENTILATED DWELLING**

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### **ABSTRACT**

This study aims to assess the transfer of outdoor air pollution into an unoccupied dwelling in Paris area with heavy traffic during winter and summer periods. CO, SO<sub>2</sub>, NO, NO<sub>2</sub>, O<sub>3</sub>, BTEX, PM<sub>2.5</sub>, black smoke index were monitored simultaneously indoors and outdoors. The indoor/outdoor relationships have been studied regarding ventilation strategies and indoor surface impact. Results show that a reduction of the average daily concentrations of NO (7-30%), SO<sub>2</sub> (33-41%), O<sub>3</sub> (80%), PM<sub>2.5</sub> (20%) and black smoke (20%) is observed indoors in reference to outdoors. The inert gas CO is integrally transferred. NO<sub>2</sub> shows no apparent difference between outdoor and indoor daily concentrations but the I/O ratio can be significantly above one in summer (high reactivity between NO and O<sub>3</sub>). In the presence of sorbing material, indoor concentrations of SO<sub>2</sub>, O<sub>3</sub> and NO<sub>2</sub> show a reduction of 75%, 90 % and 30% (in winter only for NO<sub>2</sub>) compared to outdoors.

### **INDEX TERMS**

Pollution transfer, Outdoor pollution, Chemical reactivity, Ventilation, Experimental survey.

### **INTRODUCTION**

In Paris like in other cities, people spend most of their time indoors and the relationships between outdoor and indoor urban air pollutant concentrations are more and more a subject of concern. Indeed outdoor air is essential to ventilate buildings but the parameters, which determine this transfer of outdoor pollutants into the building, are rarely well known.

An experimental study has been conducted into an unoccupied dwelling in order to analyze the impact of ventilation strategies, seasons, effect of adsorptive surfaces and chemical reactions, on the indoor concentration of pollutants related to outdoor pollution.

### **METHODS**

The dwelling chosen for the experimentation is located in a Paris area influenced by heavy traffic (close to a busy street and the ring road), providing significant levels of pollutants. Situated at the third floor of a 10-storied building built in 1955, the dwelling surface is about 55 square meters. During experiments, it was unoccupied and empty of furniture in order to minimize indoor pollutant sources.

At the initial state, the dwelling was naturally ventilated. Air renewal of the dwelling was thus controlled: the dwelling has been made airtight and the residual air leakage has been

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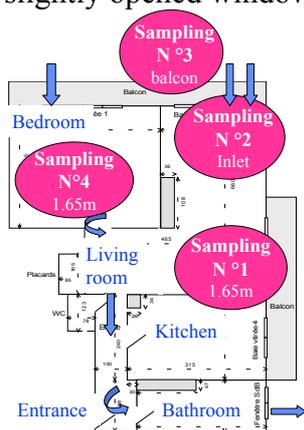
characterized using blower door and tracer gas technique. A mechanical ventilation system has been installed to allow two different controlled extract flows. During the summer experiments, measurements have also been carried out with opened windows. Detailed information on ventilation aspects of the study has been published elsewhere (Collignan et al, 2001).

Preliminary measurements were performed to verify the absence of significant horizontal and vertical gradients for gaseous pollutants (NO, NO<sub>2</sub>, BTEX) and fine particles (PM<sub>2.5</sub>).

Two measurement campaigns were conducted, one in winter (January to March 2000), and one in summer (June to August 2000). The target pollutants have been chosen to be representative of the mobile and fixed sources and of atmospheric photochemistry. The parameters of concern were carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO<sub>2</sub>), ozone (O<sub>3</sub> – only in summer), sulfur dioxide (SO<sub>2</sub> - only in winter), PM<sub>2.5</sub> particles, black smoke index (BS), temperature, humidity, wind velocity and direction. Some external and internal measurements of BTEX (benzene, toluene, ethylbenzene, xylenes) and TVOC (total volatile organic compounds) have also been realized on few days periods.

The measurements were done continuously in the dwelling (living room and bedroom) and in the closely outdoor environment (balcony) (see picture of the dwelling in Figure 1). A meteorological station has also been installed on the roof of the 10-storied building, in order to measure wind speed and direction, external and internal temperature and humidity. The sampling time steps were comprised between two minutes and one hour depending on pollutant.

For each campaign, different scenarii were tested including (1) ventilation rate at about 0.9 vol/h (2) ventilation rate at about 0.6 vol/h (3) introduction of sorbing material (acoustic tiles) in the bedroom and in the living room at two different loading rates. During the summer campaign, measurements were also conducted with two scenarii of opened windows: two slightly opened windows and one largely opened window.



**Figure 1:** Dwelling description and sampling strategy

## RESULTS

Preliminary indoor measurements show that there are no significant differences of pollutant concentrations according to the sampling location inside the dwelling. Moreover, the permeability level obtained once the dwelling has been made airtight ( $Q = 4.3\Delta P^{0.79} \text{ m}^3/\text{h}$ ,  $Q$ : extracted flow rate,  $\Delta P$ : depression) is comparable to values usually measured in new

buildings. The extraction mechanical ventilation has then been assessed using SF6 tracer gas technique. The controlled air exchange rates used for the experimental survey were 0.6 and 0.9 vol/h.

The range of the 24 hour mean values observed outdoors were:

**During the summer campaign**

CO: 0.2 – 0.8 mg.m<sup>3</sup>      NO: 2 – 42 µg.m<sup>3</sup>      NO<sub>2</sub>: 24 – 86 µg.m<sup>3</sup>  
 O<sub>3</sub>: 1 – 53 µg.m<sup>3</sup>      PM<sub>2.5</sub>: 7 – 28 µg.m<sup>3</sup>      BS: <10 – 52 µg.m<sup>3</sup>  
 Benzene: 3 - 7µg.m<sup>3</sup>      Toluene: 16 – 44 µg.m<sup>3</sup>      TVOC: 114 – 300 µg.m<sup>3</sup>

**During the winter campaign**

CO: 0.5 – 1.8 mg.m<sup>3</sup>      NO: 6 - 180 µg.m<sup>3</sup>      NO<sub>2</sub>: 36 - 123 µg.m<sup>3</sup>  
 SO<sub>2</sub> : 2 - 41 µg.m<sup>3</sup>      PM<sub>2.5</sub> : 8 - 40 µg.m<sup>3</sup>      BS : <10 – 90 µg.m<sup>3</sup>  
 Benzene: 3 - 17µg.m<sup>3</sup>      Toluene: 11 – 70 µg.m<sup>3</sup>      TVOC: 60 – 249 µg.m<sup>3</sup>

Table 1 gathers the values of the ratio C<sub>ind</sub>/C<sub>outd</sub> (I/O) for the major pollutants according to the controlled air exchange rate and the presence or not of the tested sorbing material.

**Table 1 : I/O ratio values in presence or absence of sorbing material**

Summer period	I/O ratio		
	Without sorbing material 106 m <sup>3</sup> /h*	Without sorbing material 63 m <sup>3</sup> /h*	With sorbing material 63 m <sup>3</sup> /h*
CO	1.07	1.04	1.05
NO	0.53	0.57	0.77
NO <sub>2</sub>	1.20	1.10	0.94
O <sub>3</sub>	0.21	0.20	0.05
PM <sub>2.5</sub>	0.88	0.78	0.81
BS index	0.75	0.75	0.76
Benzene	-	1.86	1.47
Toluene	-	1.07	1.28
TVOC	-	1.83	1.75
Winter period	Without sorbing material 102 m <sup>3</sup> /h*	Without sorbing material 56 m <sup>3</sup> /h*	With sorbing material 56 m <sup>3</sup> /h*
CO	1.01	1.0	1.01
NO	0.93	0.86	0.81
NO <sub>2</sub>	1.03	0.99	0.80
SO <sub>2</sub>	0.67	0.59	0.25
PM <sub>2.5</sub>	0.77	0.78	0.80
BS index	0.63	0.67	0.73
Benzene	1.09	1.78	1.28
Toluene	1.08	1.43	0.98
TVOC	1.56	1.29	1.29

\* Measured air exchange rate; 56-63 m<sup>3</sup>/h: ~ 0.6 vol/h ; 102-106 m<sup>3</sup>/h : ~ 0.9 vol/h

Different behaviors have been observed between the target pollutants and the conditions tested.

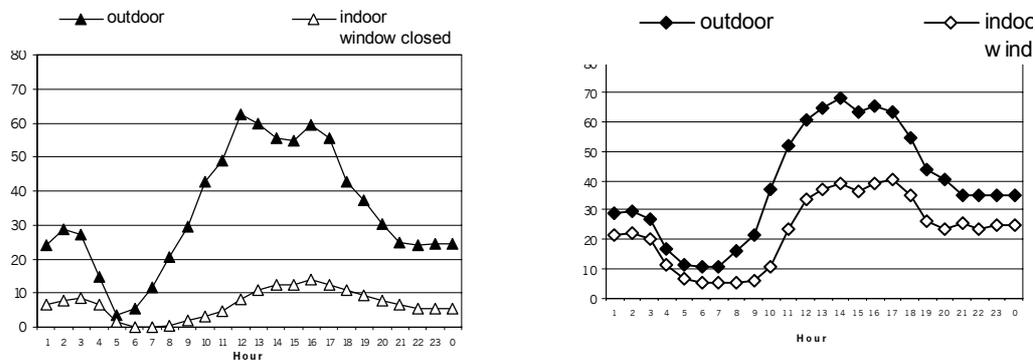
**Without introduction of sorbing material**

- ◆ CO is integrally transferred indoors regardless of seasons and ventilation rates.
- ◆ NO conc. are more reduced in summer than in winter. Indoor concentrations represent about 55% of the outdoor levels in summer while a loss of 7-14% is observed in winter.

- ◆ **NO<sub>2</sub>** generally shows no apparent difference between outdoor and indoor daily concentrations but the ratio  $C_{ind}/C_{out}$  (I/O) can be significantly above one in summer time.
- ◆ For **BTEX** and **TVOC**, the I/O values are lightly higher indoors than outdoors likely due to the presence of sources inside the dwelling.
- ◆ For **SO<sub>2</sub>**, measured only in winter, I/O values are lower than 1 for all tested conditions. The I/O ratio is 0.7 for a 0.9 vol/h air exchange rate and 0.6 for 0.6 vol/h showing the impact of ventilation conditions on the transfer of SO<sub>2</sub>.
- ◆ **O<sub>3</sub>**, measured only in summer, shows the highest change. So, a loss of about 80% of the average daily concentration is observed indoors whatever the ventilation rate was.
- ◆ **Particulate matters and BS index** show an average daily indoor concentration reduction equal to 20-25% in reference to outdoor ones. Those results are not dependent on the season tested.

Simulation of human habits in summer related to the opening of windows has no incidence on the behavior of CO and NO<sub>2</sub>. On the contrary, the I/O ratio is increased for NO and O<sub>3</sub>.

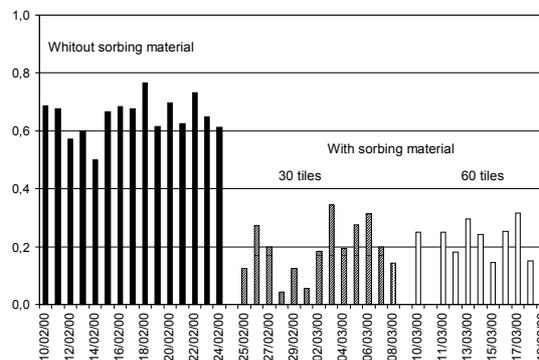
Figure 2 illustrates evolution of mean hourly indoor concentrations in summertime referring to outdoors ones when the window is closed or opened.



**Figure 2:** Impact of opening the window on the indoor ozone concentrations ( $\mu\text{g}\cdot\text{m}^{-3}$ )

**With introduction of sorbing material**

- ◆ In this case, **CO**, **NO** and **particles** levels are not affected whatever the season and the air exchange rate were.
- ◆ The behavior of **NO<sub>2</sub>** is more particular. A decrease of the levels, about 30%, was only noticed in winter.
- ◆ For **SO<sub>2</sub>** and **O<sub>3</sub>**, an average depletion of 75% and 90% respectively is observed when the sorbing acoustic tiles are introduced in the room. The SO<sub>2</sub> I/O values are shown in Figure 3.

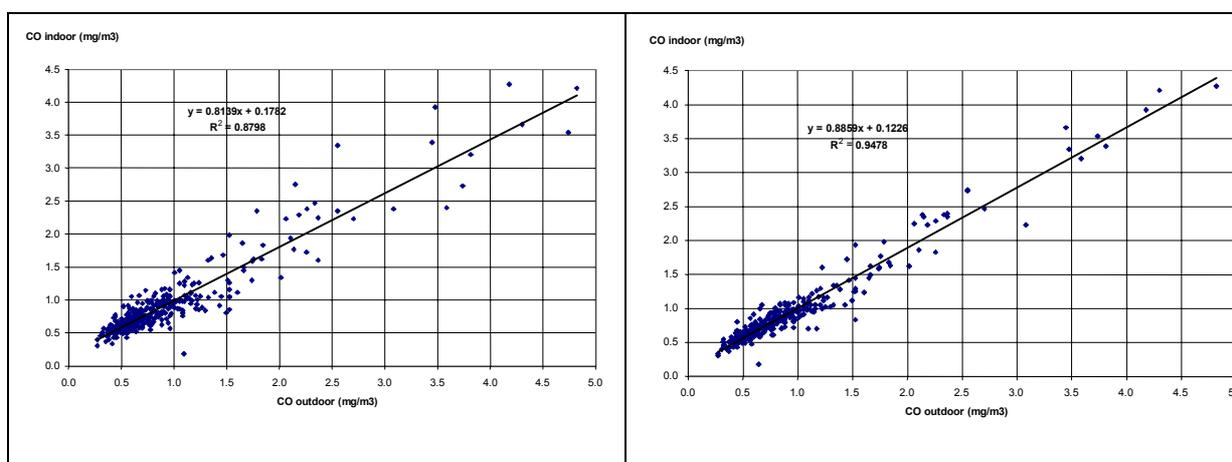


**Figure 3:** Impact of the sorbing material on the ratio I/O values for SO<sub>2</sub>

## DISCUSSION

For a non-reactive gas such as CO, the more the air renewal, the less the smooth and the delay between the outdoor and indoor pollution peak is observed. For the slightly opened windows case, the delay is less than half an hour and for the largely opened window case, outdoor and indoor concentrations are quite similar. For reactive gas as SO<sub>2</sub> and O<sub>3</sub>, the more is the air renewal, the less is the residence time of air from the outside. So, pollutant has less time to react indoors and the ratio I/O is higher.

The results show a good correlation between hourly outdoor and indoor concentrations for all pollutants whatever the tested situation (different ventilation conditions or addition of sorbing material). The correlation coefficients are much higher for non-reactive pollutants such as CO (0.97 compared to 0.94) and PM<sub>2.5</sub> (0.95 compared to 0.89) when a time difference is applied between outdoor and indoor concentrations (Figure3).



**Figure 3** : Correlation between hourly CO indoor and outdoor concentration with (left side) and without (right side) time lag (February 25th– March 10<sup>th</sup> ; air exchange rate 0.64 vol/h)

The sorbing material introduced in the rooms was aimed to artificially increase the surface of the dwelling as regard its volume and to observe the impact of high specific surface material in the pollutants transfer. The tested sorbing material (acoustic tiles) has no effect on CO, NO, PM<sub>2.5</sub> and black smokes index. On the contrary I/O ratios are significantly lower for SO<sub>2</sub>, O<sub>3</sub> and to a lesser extent for NO<sub>2</sub>. Deposition velocities have been calculated for these pollutants with or without sorbing materials respectively (0.9/0.2 m.h<sup>-1</sup> for SO<sub>2</sub>; 5/1.3 m.h<sup>-1</sup> for O<sub>3</sub>; 0.1/0 m.h<sup>-1</sup> for NO<sub>2</sub>). The results are in agreement with published data except for NO<sub>x</sub>. For O<sub>3</sub>, a recent paper (Weschler, 2000) shows that the half time of ozone indoors is determined primarily by surface removal and air exchange. In our study, with a surface-to-volume ratio equal to 2.0, the surface removal rate varies from 2.5 to 3.5 h<sup>-1</sup> range in agreement with many other studies (Weschler, 1994, Lee 1999).

In our study, indoor NO<sub>2</sub> levels are often higher than outdoors in both seasons. Reaction between NO and O<sub>3</sub> producing NO<sub>2</sub> in excess can explain these high values and was observed in other studies (Weschler, 1994; Drakou, 1998). Winter results concerning NO<sub>2</sub> are more surprising because O<sub>3</sub> levels are generally low and the dwelling is located close to high traffic roads. Generally, studies conducted with integrated passive samplers, which are not based on the same analytical principle, show lower ratio I/O (Levy, 1998) and further research is thus needed to explain this phenomena.

A mass balance model (Shair and Heitner, 1974) without chemical module, taking into account indoor sources, outdoor concentration, air exchange rate, ratio surface/volume of the room and deposition/sorption speed has been used and results have been compared to field's measurements. Good agreement was found between the model and CO, SO<sub>2</sub> and particles measurements. O<sub>3</sub>, NO and NO<sub>2</sub> shows discrepancies which confirm the chemical reactions already discussed and the need to use models that accounts for gas-phase reactive chemistry (Nazaroff, 1986; Drakou 2000).

## CONCLUSION

This experimental study is an original one in France. This work was conducted in an unoccupied and empty dwelling (in order to minimize indoor pollutant emissions) under controlled ventilation conditions. In addition, the measurements were performed during two seasons, summer and winter. Numerous urban pollutants were considered, most of them measured by mean of continuous monitoring. So, it was possible to calculate the mean daily ratios and to estimate the impact of peaks of pollution on the indoor air quality. The results are in good agreement with studies using similar measurement methods. Particularly, the results show that NO, NO<sub>2</sub> and O<sub>3</sub> interact also indoors. For these pollutants, chemical reactivity has thus to be taken into account in indoor concentration predicting models. It is important to notice that the type of indoor surfaces has a great influence on the ratio I/O for O<sub>3</sub> and SO<sub>2</sub> and in a less extent for NO<sub>2</sub>. For non-reactive pollutants such as CO and BTEX, the air exchange rate affects both the time difference between indoors and outdoors maximum concentrations and the indoor maximum values.

## ACKNOWLEDGEMENTS

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