

## Characterization of traffic-generated pollutants in Bucharest

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### RESUMEN

La directiva 96/62/EC del Consejo de la Unión Europea sobre determinación y manejo de la calidad del aire ambiental establece que deben existir planes de acción para las zonas donde la concentración de contaminantes excede los valores límite. En las áreas urbanas dichos valores límite se rebasan en especial debido al tráfico. En este trabajo analizamos la variabilidad temporal de los niveles de concentración de  $\text{NO}_x$ ,  $\text{O}_3$  y  $\text{SO}_2$  en dos cañones urbanos. La distribución de las concentraciones demuestra que el tráfico es la fuente más importante de  $\text{NO}_x$ , contaminante que se emite por la operación de los motores vehiculares. El nivel de contaminación en la calle U2 es 25% menor que el de la calle U1, aún cuando el tráfico cuantificado en la calle U2 es 50% menor que el de la U1. Esto se debe a que la geometría y la ubicación de las calles es diferente.

### ABSTRACT

European Union Council directive 96/62/EC on ambient air quality assessment and management requires the development of action plans for zones where the concentrations of pollutants in ambient air exceed limit values. In the urban areas the limit values are exceeded, especially due to the traffic. In this paper, we analyzed the temporal variability levels of concentration of  $\text{NO}_x$ ,  $\text{O}_3$  and  $\text{SO}_2$  in two street canyons. The distribution of concentrations proves that traffic is the most important source of  $\text{NO}_x$ , this pollutant being emitted during running of the vehicle engines. The level of pollution within U2 street is 25% less than U1 street, even though the measured traffic within U2 street is 50% less than within U1 street. This happens because the streets geometry and locations are different.

**Keywords:** Pollutant concentrations, traffic, urban, meteorological conditions.

### 1. Introduction

In urban areas, where the population is very numerous and the traffic is relatively high, the exposure of people to the concentrations related traffic is significant (Morris *et al.*, 1995; Fenger, 1999).

Pollutant levels depend on traffic as well as on meteorological and topographic conditions that influence pollutant dispersion or accumulation, in the studied area. For example, the background winds perpendicular to the street axis create a vortex in the street, which rallies the pollutants, increasing the pollutants levels upwind and decreasing the pollutants levels downwind (Louka *et al.*, 2000).

For reducing the pollutants emissions in the atmosphere, it is necessary to permanently monitor the air quality, which means high costs. Dispersion models are not so expensive to establish the

air quality, but they can be used only when both meteorological conditions and topography data are available. In addition, emission sources have to be known.

Main goal of our research study was to assess both the causes and the factors enhancing the pollution in an urban area. We have evaluated the concentration levels of  $\text{NO}_x$ ,  $\text{SO}_2$  and  $\text{O}_3$  in street canyons in two crossing sites in Bucharest area. The chosen streets are similar with most of the streets in the Bucharest center, considering the mean height of buildings along the street, the general street topography and pollutant concentrations. Therefore, results of this study can be applied to other streets. The characteristics of the sites and the traffic data used are presented in Section 2. The results of the correlation between traffic and pollutant concentrations are shown in Section 3. Here we also introduced a normalized and non-dimensional parameter  $K$  to characterize the air quality in this urban area. This parameter is more accessible for local authorities in the decisional acts related to urban air quality. In the final section of the paper, some conclusions are presented.

## 2. The streets and the traffic data

### 2.1 Characteristics of the sites

The field study was conducted for a year in two junctions which can be considered hot spots, continued with two streets, in this paper U1 (Carol I Street), located to  $90^\circ$  from North (Fig. 1) and U2 (Dacia Avenue) located to  $135^\circ$  from North (Fig. 2), in the city of Bucharest, Romania. The first junction is wider than the second, but the street canyon U1 is shorter than U2 and the buildings surrounding the street are of equal height. U2 is a street canyon with buildings of different heights and different roof geometry. Consequently, the aspect ratio  $H/W$  of the streets is different ( $H$  is the average height of the canyon walls and  $W$  is the canyon width) (Berkowicz *et al.*, 2002). The measurements of pollutant concentrations were made in 2002 year.



Fig. 1 Nicolae Bălcescu and Carol I Street.



Fig. 2. Piata Romana junction, continued with Dacia Avenue.

## 2.2 Traffic measurements

Traffic measurements have been done using the devices from a mobile laboratory belonging to Romanian Auto Register (RAR). For both areas chosen, we measured the traffic flow (number of vehicle/hour) and concentration of pollutants like  $\text{NO}_2$ ,  $\text{O}_3$  and  $\text{SO}_2$ . The instruments used are an automatic machine Horiba, which records the pollutants concentrations near the breathing level (situated at 1.5 m height related to ground) (Tripathi *et al.*, 2004) and a Vaisala weather station, which records the meteorological parameters (temperature, humidity, solar radiation, wind speed and wind direction).

Wind flow and pollutant dispersion within continuous street canyons essentially depend on the aspect ratio, the street length and building roof geometry (Theurer, 1999).

In Figure 3, it is shown the traffic flow in junction and crossing U1 for each day of the week.

The graph shows higher traffic in weekdays, and decrease by 50% in weekends when people leave urban areas. Figure 3 points out the morning peak, around nine o'clock and the afternoon peak during weekdays.

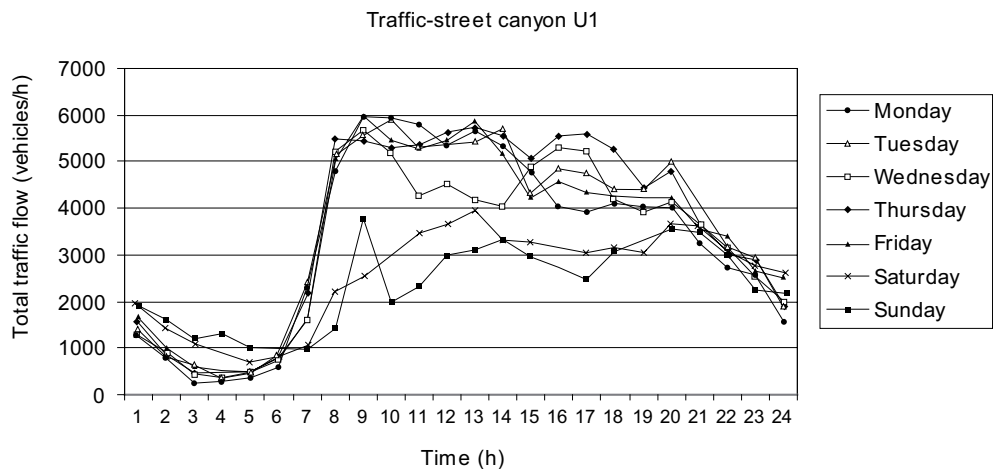


Fig. 3. Traffic frequency in the street canyon called U1 for each day of the week, annual averages.

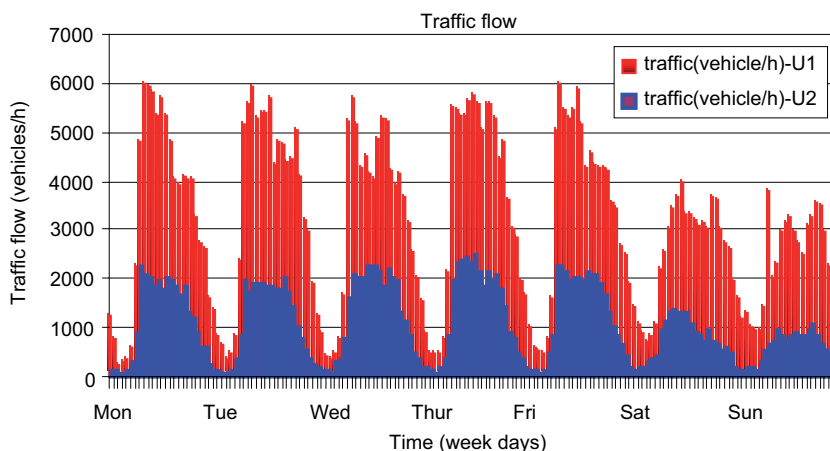


Fig. 4. Traffic frequency for U1 and U2 for each day of the week, annual averages.

The traffic flow is different for the selected streets (Fig. 4). In U2 street canyon, the measured number of vehicles is 50% smaller than in U1. The daily trend of the traffic in both streets is similar. In both streets the decreasing trend of traffic is also observed during the weekend.

### 3. Results and discussions

#### 3.1 Air pollutants and traffic

Air pollution from traffic is a complex mixture of many chemicals, but nitrogen oxides ( $\text{NO}_x$ ) proved to be a good indicator of traffic pollution in urban areas (Briggs, 1997; Nieuwenhuijsen, 2004). The primary emission from traffic is mostly nitric oxide (NO), which is transformed to  $\text{NO}_2$  by atmospheric photochemical reactions, influenced by ozone concentrations.

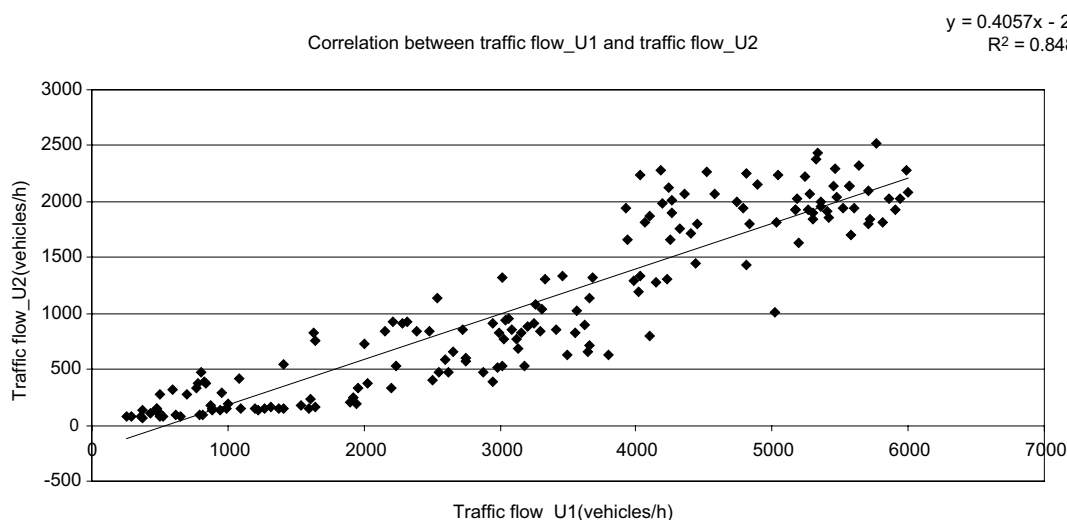


Fig. 5. Correlation between traffic flow\_U1 and traffic flow\_U2, annual mean values.

The correlation between traffic flow-U1 and traffic flow-U2, represented in Figure 5 is relatively good, but it was influenced by traffic congestions. Hourly average concentration data ( $O_3$  and  $NO$ ), measured for weekdays and weekend in U1 street are plotted in Figure 6. The variability of traffic and the  $NO$  concentration is similar, emphasizing that the traffic is the most important source of  $NO$ . The  $O_3$  concentration values are small when the  $NO$  concentration values are large due to the processes of  $NO_2$  generation (Fig. 6).

Hourly averages concentration data ( $NO_x$  and  $SO_2$ ), measured for weekdays and weekend in U1 street are plotted in Figure 7. The graphs show the temporal variability of the pollutants levels. Therefore, we can see very high levels recorded for  $NO_x$  (up to  $1500 \mu g/m^3$ ), while for  $SO_2$  the values are below  $30 \mu g/m^3$ .

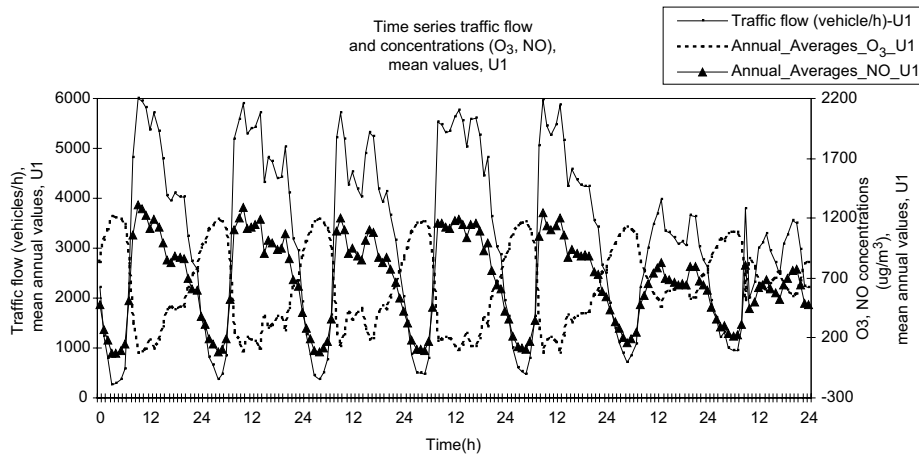


Fig. 6. Hourly average concentrations data ( $O_3$ ,  $NO$ ) in the U1 street and traffic flow.

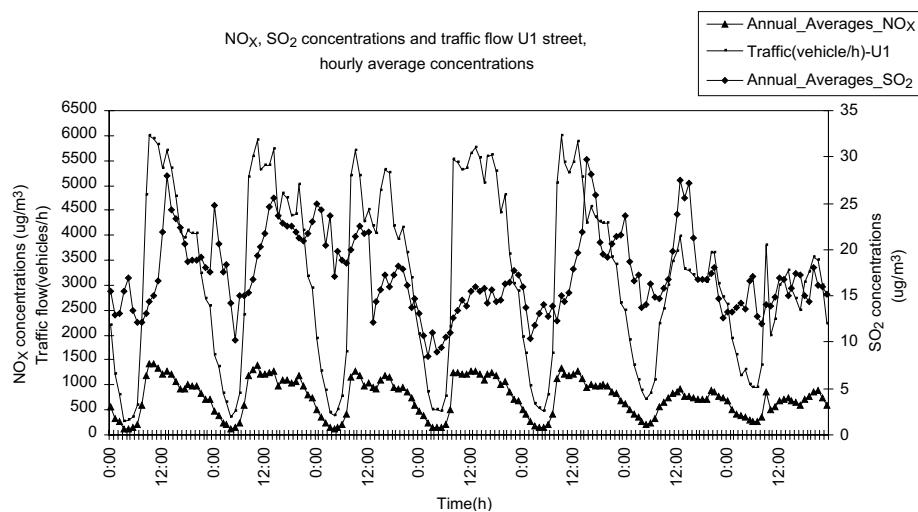


Fig. 7. Hourly average concentrations data ( $NO_x$ ,  $SO_2$ ) in the U1 street and traffic flow.

Figures 8 (U1) and 9 (U2) show a very good correlation between traffic flow and nitrogen oxides (NO and NO<sub>2</sub>) concentrations in the street. Such distribution of concentrations proves that traffic is the most important source of NO<sub>x</sub>, this pollutant being emitted by the vehicle engines during their running.

The different shapes of the graphs for the U1 and U2 streets (Figs. 8 and 9) is due to the influence of the traffic flow and the topographic characteristics on the NO and NO<sub>2</sub> concentrations in the street.

Figure 10 (U1 street) shows anti-correlation between traffic flow and O<sub>3</sub>. This is because the traffic determines NO emissions and NO uses ozone in the photochemical processes.

The correlation between traffic flow and SO<sub>2</sub> concentrations was plotted in Figure 11. The weak correlation proves that traffic is not a source of this pollutant and the streets are not next to an industrial area.

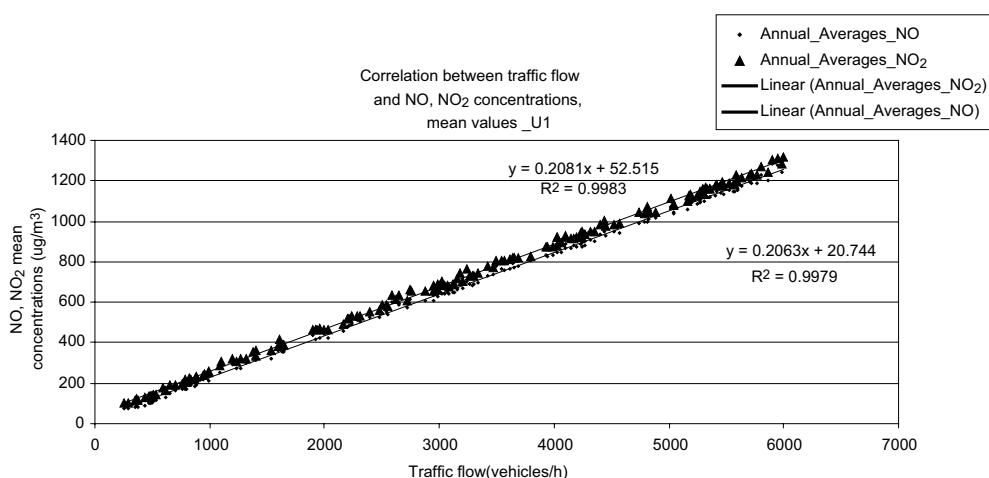


Fig. 8. Correlation between traffic flow (U1) - NO and NO<sub>2</sub> concentrations, annual mean values.

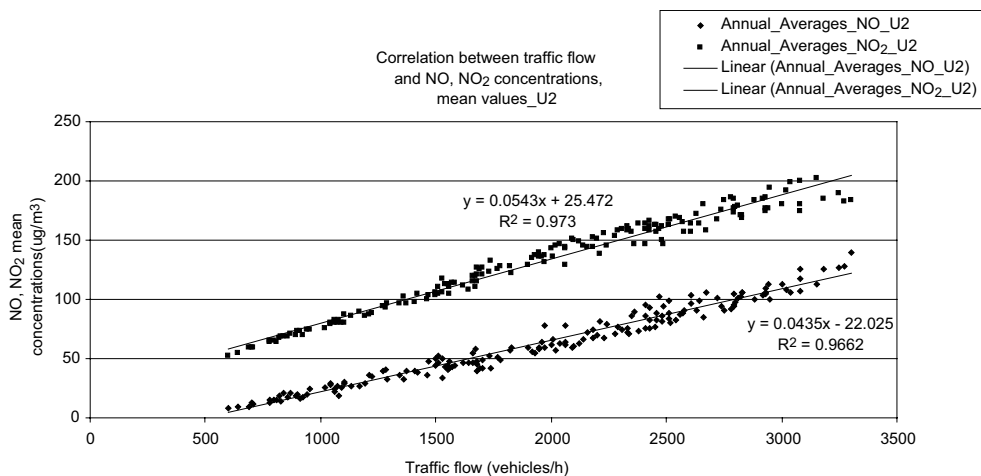


Fig. 9. Correlation between traffic flow (U2) - NO and NO<sub>2</sub> concentrations, annual mean values.

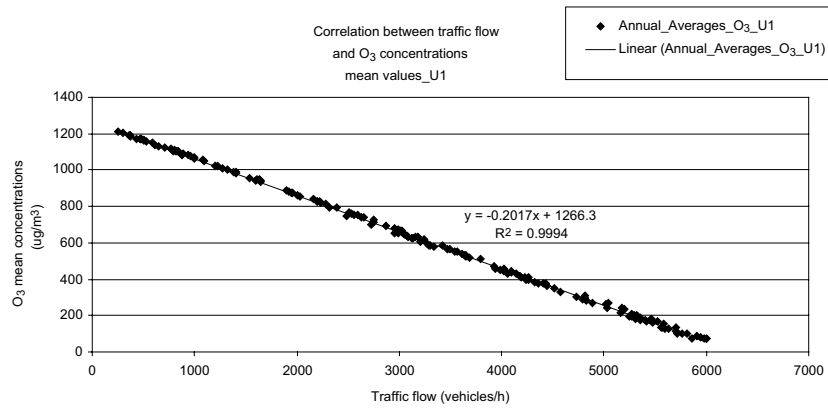


Fig. 10. Correlation between traffic flow (U1) and O<sub>3</sub> concentrations, annual mean values.

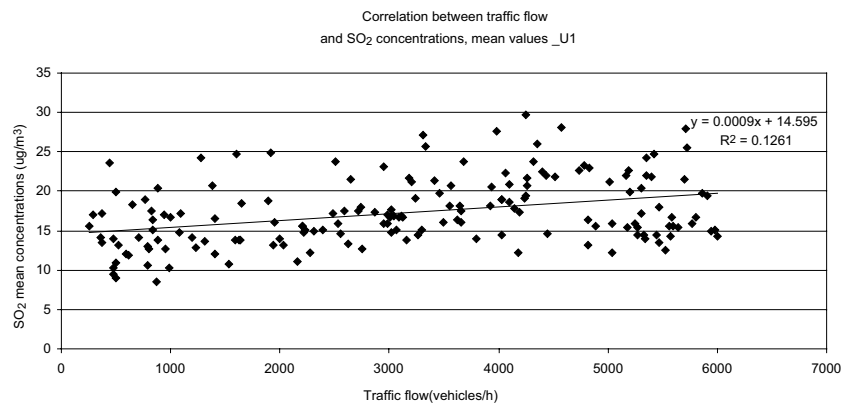


Fig. 11. Correlation between traffic flow (U1) and SO<sub>2</sub> concentrations, annual mean values.

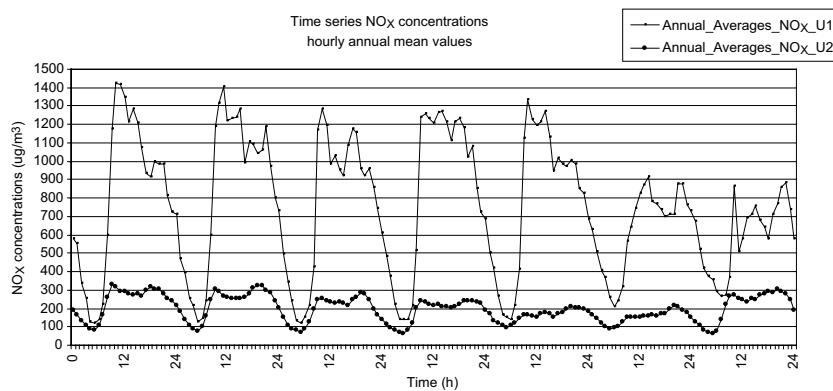


Fig.12. NO<sub>x</sub> concentrations, hourly annual mean values, from Monday to Sunday, for U1 and U2.

The graphs presented in Figure 12 show that the level of pollution within U2 street is 25% less than within U1 street, even though the traffic within U2 street is 50% less than within U1 street (Fig. 4). The streets geometry and locations are different and they have a great influence on the pollution level.

### 3.2 The wind influence

Direction and intensity of the wind significantly influence the state of the atmosphere in urban areas, especially in canyon streets and consequently dispersion of pollutants (Kim and Baik, 2004).

To analyze the influence of the wind on the behaviour of pollutants in the street canyons, we have selected a short period with higher pollutant concentration, January 19-25 (Fig. 13).

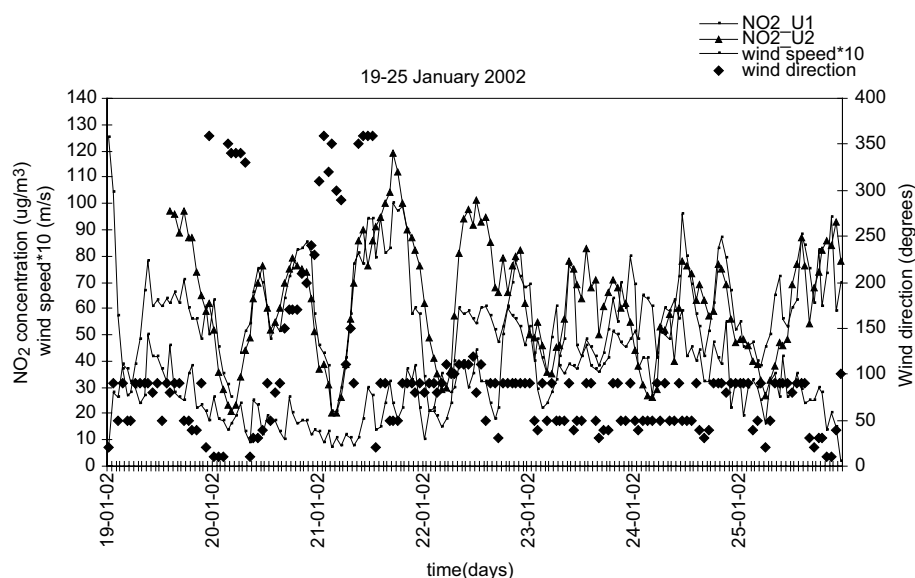


Fig. 13. Hourly variation of  $\text{NO}_2$  concentrations and wind characteristics for U1 and U2 on 19-25 January 2002.

Generally, the behaviour of the concentration values is known: when the wind speed is higher, the dispersion, due to increased turbulence, is more active and the pollutants dilution is better, resulting in low levels of pollution (Kim and Baik, 2004); when the wind speed is lower, elevated levels of pollutants are measured.

Wind rose shows that the wind blows especially in sector  $60^\circ$  to  $90^\circ$  and the higher wind speed was recorded from  $60^\circ$  (Fig. 14). The direction of U1 street canyon is similar with the dominant wind direction for this period and  $\text{NO}_2$  concentration values are smaller than those for U2 street, however the traffic is less in U2 street (Fig. 4, selected area). It means that the wind enhances the turbulence and consequently the pollutant dispersion within U1 street.

Generally, the annual wind rose (Fig. 15) shows that the wind blows, over 16%, on the direction of  $110^\circ$ , 16% on  $35^\circ$ , 16% on  $285^\circ$  toward the north. It means that the wind is neither perpendicular to nor parallel with the streets (Figs. 1 and 2 for streets location). In this situation, in the street, a

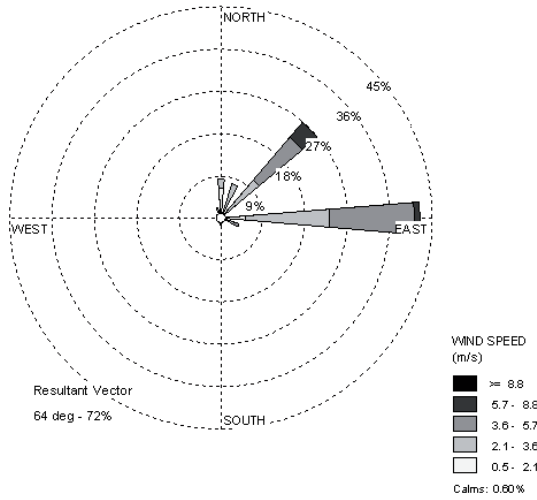


Fig. 14. Wind rose on 19-25 January 2002.

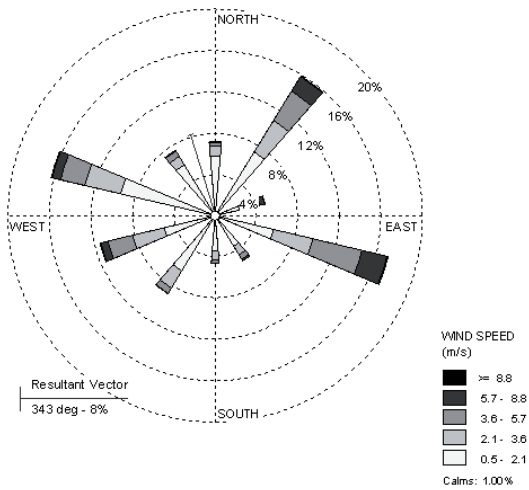


Fig.15. Wind rose average for 2002.

helical vortex rises, which advances along the street, carrying on the pollutants. The highest wind speed was recorded from 240° (11.7m/s).

### 3.3 The $K$ parameter to characterize the air quality

To characterize the air quality in an urban area we have introduced the normalized non-dimensional parameter  $K$ , because is more accessible for local authorities in the decisional acts related to urban air quality. This is defined as:

$$K = \frac{CU_{ref}HL}{Q}$$

where  $C$  is the raw concentration of NO ( $\mu\text{g}/\text{m}^3$  converted from ppb),  $U_{ref}$  (m/s) is the wind speed measured at the mast,  $H$  (m) is the height of the canyon and  $Q/L$  (mg/s/m) is the NO emission per unit length along the canyon (Fig. 16a and b) (Meroney *et al.*, 1996).

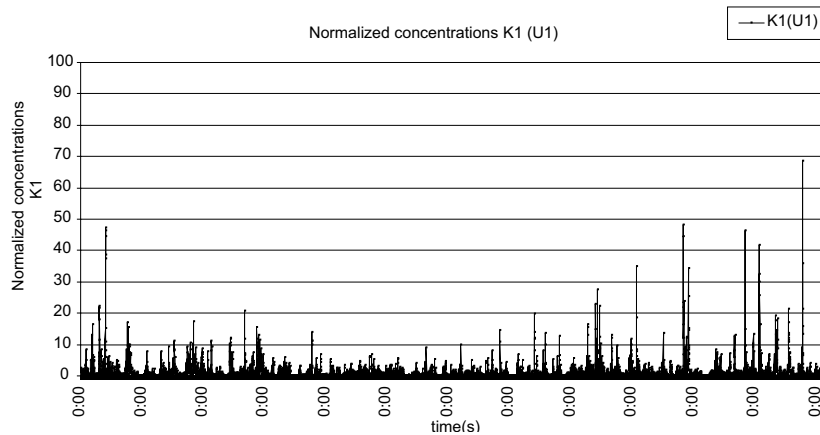


Fig.16a. Temporal variation of the normalized concentration, K1  
(on time axis 0:00 means zero hour each 30 days)

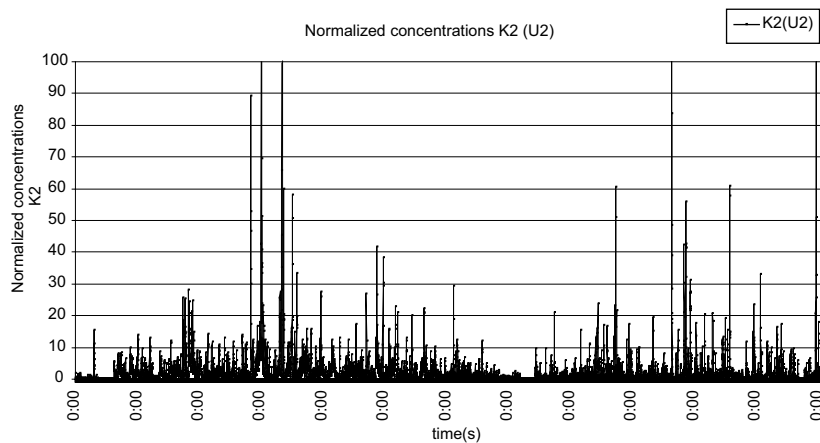


Fig. 16b Temporal variation of the normalized concentration, K2  
(on time axis 0:00 means zero hour each 30 days)

The actual emissions along the streets during this experiment were not possible to be directly measured, so an estimate from the RAR (Romanian Auto Register) has been used.

For simplicity, a linear relationship between the emissions and the total traffic flow is assumed, i.e.,

$$\frac{Q}{L} \approx eT$$

where T is the total traffic flow in vehicles/h and e is an averaged emission factor for vehicles emission in the street. A value of 7.81  $\mu\text{g}/\text{m}/\text{veh}$  was derived for e on U1 and U2 during peak flows, which is based on the vehicle classifications of mean traffic flow in U1 and U2, from a large number of traffic counts and the emissions database from the RAR. Using such a simple model for the emissions will exclude any effects due to idling or acceleration within the traffic flow.

The normalized concentrations  $K$  (non-dimensional), for U1 ( $K_1$ ) and U2 ( $K_2$ ) were plotted in Figure 16a and b. These graphs show a very strong temporal variability especially for  $K_2$ . All the values, especially the extreme values for  $K_2$  are higher than for  $K_1$  because the traffic congestions and the characteristic stop-start traffic flows, within U2 provide substantial variability to the concentrations. This means that the fluidization within U1 is better than within U2.

#### 4. Summary and conclusions

In this paper, the influence of traffic and wind speed and direction on the temporal variability of  $\text{NO}_x$ ,  $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{O}_3$  and  $\text{SO}_2$  have been investigated.

The results show relatively high levels of nitrogen oxides and traffic flow, around two times a day: in the morning between 7:00 and 10:00 local time, when people go to work, and in the afternoon, between 16:00 and 19:00 local time, when people go back home.

We have noticed a good correlation between pollutants concentrations in the street ( $\text{NO}$ ,  $\text{NO}_2$ ) and traffic flow, despite the fact that the nitrogen oxides participate in photochemical reactions. These results prove that traffic is the most important source of  $\text{NO}_x$ , emitted by running engines.

The influence of traffic flow characteristics on nitrogen oxides concentrations varied for different street canyon geometries. Therefore, the level of pollution within U2 street is reduced to 25% than within U1 street, even if the traffic within U2 street is reduced to 50% than within U1 street.

The wind influence is also observed in our analysis (Fig. 13). So, wind has a significant, but local effect on air pollution concentrations.

The traffic congestions and the stop-start traffic flows lead to high pollution and strong temporal variability (Fig. 16a and b), because they enhanced emission rates from vehicle engines. This means that the fluidization of the traffic is very necessary.

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